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NINTH SUMMER MEETING OF THE ASSOCIATION

The ninth summer meeting of the Mathematical Association of America was held at Cornell University, Ithaca, N.Y., on Tuesday and Wednesday, September 8-9, 1925, in conjunction with the summer meeting and colloquium of the American Mathematical Society. The total attendance at the two sessions of the Association was 175, including the following 129 members:

C. R. ADAMS, Brown University.
R. P. AGNEW, Cornell University.
O. P. AKERS, Allegheny College.
W. E. ANDERSON, Miami University.
R. C. ARCHIBALD, Brown University.
CLARA L. BACON, Goucher College.
GRACE M. BAREIS, Ohio State University.
ETHELWYNN R. BECKWITH, Western Reserve University.
B. R. BEISEL, Cornell University.
E. T. BELL, University of Washington.
A. A. BENNETT, Lehigh University.
T. L. BENNETT, University of Illinois.
G. D. BIRKHOFF, Harvard University.
G. A. BLISS, University of Chicago.
S. L. BOOTHROYD, Cornell University.
H. S. BROWN, Hamilton College.
MARGARET BUCHANAN, West Virginia University.
W. G. BULLARD, Syracuse University.
R. W. BURGESS, Western Electric Co., New York.
W. H. BUSSEY, University of Minnesota.
A. D. CAMPBELL, University of Arkansas.
I. S. CARROLL, Syracuse University.
E. H. CARUS, La Salle, Illinois.
W. B. CARVER, Cornell University.
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JULIA T. COLPITTS, Iowa State College.
J. L. COOLIDGE, Harvard University.
LENNIE P. COPELAND, Wellesley College.
N. A. COURT, University of Oklahoma.
E. F. COX, Cornell University.
F. F. DECKER, Syracuse University.
W. W. DENTON, University of Michigan.
H. A. DOBELL, Colgate University.
L. W. DOWLING, University of Wisconsin.
ARNOLD DRESDEN, University of Wisconsin.
OTTO DUNKEL, Washington University.
J. A. EIESLAND, West Virginia University.
L. P. EISENHART, Princeton University.
G. C. EVANS, Rice Institute.
G. W. EVANS, Charlestown High School, Boston, Mass.
H. S. EVERETT, Bucknell University.
FAY FARNUM, Cornell University.
PETER FIELD, University of Michigan.
W. B. FORD, University of Michigan.
TOMLINSON FORT, Hunter College.
T. C. FRY, Bell Tel. Laboratories, New York.
M. G. GABA, University of Nebraska.
A. S. GALE, University of Rochester.
W. V. N. GARRETSON, Rutgers College.
D. C. GILLESPIE, Cornell University.
R. E. GILMAN, Brown University.
O. E. GLENN, University of Pennsylvania.
J. W. GLOVER, University of Michigan.
W. C. GRAUSTEIN, Harvard University.
C. E. HARRINGTON, University of Buffalo.
E. R. HEDRICK, University of California, So. Branch.
M. E. HEKIMIAN, Cornell University.
T. H. HILDEBRANDT, University of Michigan.
EINAR HILLE, Princeton University.
T. H. HOLLCROFT, Wells College.
ANNA M. HOWE, Tulane University.
W. A. HURWITZ, Cornell University.
M. H. INGRAHAM, University of Wisconsin.
DUNHAM JACKSON, University of Minnesota.
B. W. JONES, Western Reserve University.
O. D. KELLOGG, Harvard University.
B. F. KIMBALL, Cornell University.
H. W. KUHN, Ohio State University.
W. D. LAMBERT, Coast and Geodetic Survey, Washington.
SOLOMON LEFSCHETZ, Princeton University.
C. A. LINDEMANN, Bucknell University.
RICHARD LONG, University of Rochester.

R. S. LUBBEN, University of Texas.
W. T. MACCREADIE, Cornell University.
C. C. MACDUFFEE, Ohio State University.
J. V. MCKELVEY, Iowa State College.
MARTHA M. MCKELVEY, Iowa State College.
HELEN A. MERRILL, Wellesley College.
A. D. MICHAL, Rice Institute.
G. A. MILLER, University of Illinois.
NORMAN MILLER, Queens University.
E. C. MOLINA, Amer. Tel. & Tel. Co., New York.
EUGENIE M. MORENUS, Sweet Briar College.
C. L. E. MOORE, Mass. Inst. of Technology.
C. N. MOORE, University of Cincinnati.
RICHARD MORRIS, Rutgers College.
D. S. MORSE, Union College.
MARSTON MORSE, Brown University.
F. H. MURRAY, Dalhousie University.
J. J. NASSAU, Case School of Applied Science.
G. D. OLDS, Amherst College.
H. L. OLSON, Michigan State College.
HELEN B. OWENS, Ithaca, N. Y.
F. W. OWENS, Cornell University.
MARGARET C. PACKER, Hood College.
L. R. PERKINS, Middlebury College.
H. PORITSKY, Cornell University.
ARTHUR RANUM, Cornell University.
S. E. RASOR, Ohio State University.
C. E. RHODES, Heidelberg University.
R. G. D. RICHARDSON, Brown University.
HORTENSE RICKARD, Ohio State University.
H. L. RIETZ, University of Iowa.
G. M. ROBISON, Duke University.
E. D. ROE, JR., Syracuse University.
J. ROSENBAUM, Milford, Conn.
GEORGE SAUTÉ, Brown University.
G. T. SELLEW, Knox College.
H. C. SHAUB, Cornell University.
W. A. SHEWHART, Bell Tel. Laboratories, New York.
J. A. SHOHAT, University of Michigan.
H. E. SLAUGHT, University of Chicago.
L. L. SMAIL, University of Texas.
CLARA E. SMITH, Wellesley College.
G. W. SNEDECOR, Iowa State College.
VIRGIL SNYDER, Cornell University.
A. HELEN TAPPAN, Iowa State College.
MARIAN W. TORREY, Goucher College.
H. S. VANDIVER, University of Texas.
ROXANA H. VIVIAN, Wellesley College.
W. J. WALLIS, High Schools, Washington, D. C.
C. W. WATKEYS, University of Rochester.
H. E. WEBB, Central High School, Newark, N. J.
J. H. M. WEDDERBURN, Princeton University.
LOUIS WEISNER, University of Rochester.
W. D. A. WESTFALL, University of Missouri.
C. O. WILLIAMSON, College of Wooster.
ELIZABETH W. WILSON, High Schools, Washington, D. C.
C. H. YEATON, Oberlin College.

The arrangements for the various meetings of the week and for the convenience, comfort, and pleasure of the members and their families and friends seemed to be carried out to perfection under the guidance of Professor W. A. Hurwitz, chairman of the committee. The dormitory accommodations in Sage College were convenient, comfortable, and greatly appreciated, and the meeting rooms in the Baker Laboratory were well suited to their purpose.

The provision for entertainment included a reception in Sage College on Tuesday evening where President Farrand on behalf of Cornell University welcomed in felicitous words the visiting mathematicians and responses were made by the presidents of the two organizations, Professors G. D. Birkhoff and J. L. Coolidge; an excursion on Thursday afternoon to beautiful Enfield Glen under the direction of Professor and Mrs. F. W. Owens; a delightful afternoon tea on Friday at the Ithaca Country Club with Mrs. J. H. Tanner, Mrs. Virgil Snyder and other faculty wives as hostesses; a visit to the observatory on Friday evening, and an organ recital by Professor W. C. Ballard of the Electrical Engineering department. All of these arrangements were greatly enjoyed and formal resolutions of appreciation were tendered to the committee and all who rendered assistance.

The joint dinner on Wednesday evening was attended by 174, including members of the two organizations and their families and friends. Professor H. E. Slaught presided and short talks were given by Professors Tomlinson Fort, A. A. Bennett, E. T. Bell, W. C. Graustein, Lennie P. Copeland, and W. B. Ford. An honored guest of the evening was Dr. Edward H. Carus, son of Mrs. Mary Hegeler Carus whose gift to the Association made possible the Carus Mathematical Monographs.

The two sessions of the Association for the reading of papers were held on Tuesday and Wednesday mornings. The program was arranged by Professors J. W. Bradshaw, University of Michigan, Mary E. Wells, Vassar College, and W. H. Roever, chairman, Washington University. The following papers were read at the two sessions:

1. "Elementary geometry and its foundations," by Mr. H. E. WEBB, Central High School, Newark, N. J.

2. Discussion of Mr. Webb's paper by Professor NATHAN ALTSHILLER-COURT, University of Oklahoma.

3. "The mathematical basis of art," by Professor G. D. BIRKHOFF, Harvard University.

4. "Certain applications of differential and integral calculus to actuarial science," by the retiring president, Professor H. L. RIETZ, University of Iowa.

5. "The College Entrance Examination Board from behind the scenes," by Professor VIRGIL SNYDER, Cornell University.

6. "Outlines of fields of research: projective geometry," by Professor L. W. DOWLING, University of Wisconsin.

7. "Mathematical problems which arise in a research laboratory," by Dr. T. C. FRY, Western Electric Company, New York, N.Y.

Professor J. L. Coolidge, president of the Association, presided at both sessions. Following are brief abstracts of the papers, numbered as in the foregoing list:

(1) Mr. Webb contended that elementary geometry as presented in American text books suffers from too meticulous a demand for nicety of form and at the same time from serious errors in the logical development of the subject. These have arisen from the effort to simplify Euclid's *Elements* without impairing his method of procedure. Recent advances in the field of synthetic projective geometry and in the foundations of geometry have served to correct the few errors in the Euclidean text and the many in those of later date, but have given the subject a form which is beyond the powers of a beginner. The remedy proposed is an arbitrary list of improved propositions which would include besides the familiar assumptions of elementary plane geometry many propositions which are now proved but are quite obvious, and also certain propositions which are now by custom assumed tacitly, but which are readily

understood and actually demanded for complete demonstration. In preparing such a list, regard should be had for the development of synthetic projective geometry, one purpose of which would then be to establish logically either as independent assumptions or as demonstrated theorems the propositions thus laid down. A typical list was submitted.

(2) In opening the discussion of Mr. Webb's paper, Professor Altshiller-Court stated that there are several fundamental reasons why the traditional course in elementary geometry should be changed. We know now vastly more mathematics, and in particular much more elementary geometry than was known in the time of Euclid. The *Elements* of Euclid was written for mature men of high intellectual development while we are teaching the subject to boys and girls of a tender age. The more intuitional theorems ought to be assumed without proof. Other theorems, like those concerning areas and volumes, should be stated in arithmetic and their proofs given in the calculus. The axioms should be stated as explicitly as possible, and no vicious circles in the demonstrations should be tolerated. However, in view of the limited mathematical experience of the beginner, it would be a harmful exaggeration to put into the proofs of elementary geometry all the circumspection that might be required of them by a trained mathematician who is familiar, say, with the elliptic and hyperbolic geometries.

(3) In his lecture on "The mathematical basis of art," Professor Birkhoff discussed the possibility of quantitatively estimating the comparative aesthetic value of simple works of art of a prescribed type. He expressed the view that such a measure might be obtained as the ratio O/C, where O is the order and C is the complexity of the work of art. Definite methods of analysis were presented in the case of tiles, vases, and paintings, and illustrations were given by means of lantern slides.

(4) The address of Professor Rietz appears in full in this number.

(5) Professor Snyder explained informally the method of procedure observed by the College Entrance Examination Board in the annual examinations. The subject matter in each subject is minutely defined by the syllabus prepared by various agencies appointed by organizations other than the Board; the question papers are submitted to a committee of revision to insure that each question is within the proper definition; every answer having a rating of not over sixty is not only re-read, but after having been re-read and the two ratings minutely compared, every such paper is then again read by a special committee and all of the ratings are adjusted to a common basis. Signed complaints, either from candidates or from others, are carefully considered. In fact every effort is made to make the tests as fair and as indicative of the candidate's proper standing as can possibly be made.

(6) The address of Professor Dowling appeared in the MONTHLY for December, 1925.

(7) Dr. Fry outlined a number of problems which grow out of the activities of the Bell Telephone System, and which illustrate the wide range of mathematical subject matter that finds a use in industrial work. Among them were: The use of *a posteriori* probability in interpreting factory inspection data; the use of *a priori* probability in the design of telephone exchanges; the use of function theory, integral equations, operational calculus, and generalized Fourier integrals in the solution of transmission problems; continued fraction expansion of functions and divergent series in the design of networks with preassigned impedances; analysis situs in the classification of impedance nets; and multiform solutions of differential equations in diffraction problems.

Considerable discussion arose in connection with Mr. Webb's paper, participated in by Professors Eisenhart, Jackson, Slaught and others. A resolution to have a special committee consider and report upon the whole question of the teaching of geometry in the secondary school was referred to the Trustees for final action. At a later meeting of the Trustees, it was voted to postpone for the present any official action of the Association with reference to reform in the teaching of elementary geometry, it being felt that the report of the National Committee and the subsequent report of the College Entrance Examination Board should be allowed to operate unhampered for a reasonable period before any further action by the Association is taken.

Much regret was expressed on all sides over the enforced absence of the secretary, Professor W. D. Cairns, it being the first meeting of the Association which he has missed since its organization nine years ago.

MEETINGS OF THE BOARD OF TRUSTEES

The Trustees of the Association held two meetings at Ithaca. President Coolidge presided and ten members were present at each session. The following are the chief items of business transacted, though informal discussion of many items of interest to the Association occupied serious attention during the two sessions.

The following thirty persons and one institution were elected to membership on applications duly certified:

To Individual Membership

C. W. ANDREWS, A.M. (Harvard); LL.D. (Northwestern). Librarian, The John Crerar Library, Chicago, Ill.

E. P. BLACKBURN, A.B. (Oakland City Coll.) Wadesville, Ind.

STANLEY BOLKS, M.S. (Iowa State). Instr., Purdue Univ., W. LaFayette, Ind.

MARY E. CLARKE, M.S. (Kentucky). Teacher, Senior High School, Lexington, Ky.

E. F. COX, Ph.D. (Cornell). Math. and Physics, West Virginia Coll. Inst., Institute, W. Va.

D. A. FLANDERS, A.B. (Haverford). Prof., Texas Tech. Coll., Lubbock, Texas.

H. A. FOSTER, A.B. (Baylor). Instr., Physics, A. and M. Coll. of Texas, College Station, Texas.

A. H. FOX, A.B. (Western Reserve). Instr., Oberlin College, Oberlin, Ohio.

GEORGE HARTNELL. Observer in Charge, Magnetic Observ., Cheltenham, Md.

T. W. HATCHER, M.E. (Va. Polytech. Inst.); M.S. (Iowa State Coll.) Asst. Prof., Virginia Polytech. Inst., Blacksburg, Va.

M. E. HEKIMIAN, C.E., A.M. (Cornell). Hotel Bevan, Larchmont, N. Y.

V. B. HINSCH, M.E. (School of Mines). Asso. Prof., School of Mines and Metallurgy, Rolla, Mo.

W. R. HUTCHERSON, A.M. (Kentucky). Asso. Prof., Berea Coll., Berea, Ky.

FRED KADERLI. Teacher, High School, San Marcos, Texas.

KATHERINE D. KIENZLE, A.B. (Louisville). Teacher, Margaret Hall, Versailles, Ky.

S. B. LITTAUER, Ch.E. (Rensselaer). Teacher of Physics, Boys' High School, Brooklyn, N.Y.

C. A. MANEY, M.S. (Chicago). Prof., Transylvania Coll., Lexington, Ky.

E. W. MARTIN, M.S. (Illinois). Prof. and Head of Dept., Western State Coll., Gunnison, Colo.

G. T. NEWTON, A.B. (Texas). Head of Dept. of Math., High School, Cameron, Texas.

E. K. PAXTON, A.M. (Washington and Lee; Columbia). Asso. Prof., Washington and Lee Univ., Lexington, Va.

R. I. PEPPER, A.B. (Centre Coll.) Teacher, High School, Paris, Ky.

A. J. PYKE, B.A. (Toronto). Prof., Univ. of Saskatchewan, Saskatoon, Sask., Canada.

C. E. RHODES, A.B. (Cornell). Instr., Heidelberg Univ., Tiffin, Ohio.

LAURA RIESBECK, B.S. in Educ. (Ohio Univ.) 1001 Greenwood Ave., Zanesville, Ohio.

L. R. SALVOSA, A.B. (Philippines); Grad. U.S. Milit. Acad. Prof. Math. and Eng., Los Baños Coll., Laguna, P.I.

F. A. SCOTT, A.M. (Columbia). Prin., High School, Paris, Ky.

J. S. SEWELL, Grad. U.S. Milit. Acad. Pres., Ala. Marble Co., Birmingham, Ala.

W. A. SHEWHART, Ph.D. (California). Bell Telephone Labs., 463 West St., New York, N.Y.

V. A. TAN, A.M., C.E. (Cornell), Ph.D. (Chicago). Prof., Univ. of the Philippines, Manila, P.I.

L. D. WILLS, A.B. (Reed). Part-time Instr., Princeton Univ., Princeton, N.J.

To Institutional Membership

BUTLER COLLEGE, Indianapolis, Ind.

This makes a total of 146 individuals and seven institutions elected since the publication of the last Register in November, 1924. It was voted to publish a new Register.

Invitations for future meetings were received and accepted as follows: the summer meeting in 1926 at Ohio State University, Columbus, Ohio; the summer meeting in 1927 at the University of Wisconsin. The annual meeting in December, 1925 had already been fixed for Kansas City, Missouri, and the annual meeting in 1927 at the University of Pennsylvania, Philadelphia, Pennsylvania, both in affiliation with the American Association for the Advancement of Science. The Program Committee for the Kansas City meeting is L. W. Dowling, chairman; W. C. Brenke, Olive C. Hazlett, G. H. Light.

It was reported by the committee on Carus Monographs that 879 copies of the first monograph had been taken by members of the Association and that about 375 had been sold to the general public by the Open Court Publishing Company. The receipts from sales to the members, after payment of the honorarium to the authors, are deposited to the credit of the Carus Publishing Fund in the treasury of the Association. This fund now amounts to $2099.18.

The second monograph on *Functions of a Complex Variable* by Professor D. R. Curtiss will be ready for the printers early in November and should be ready for distribution by February, 1926.

Owing to the fact that President Coolidge will be out of the country at the time of the next summer meeting, it was voted that he should deliver his retiring address at the annual meeting in Kansas City. His address will be on "Robert Adrain and the beginnings of American mathematics."

Professor Archibald reported that the contract has been let for the publication of the *Rhind Papyrus* by Chancellor Chace, of Brown University, under the auspices of the Association. There will be 550 sets for sale at cost by the Association to its members. A committee consisting of Professors Archibald, Cairns and Slaught was appointed to administer the details of this great benefaction to the Association. Professor Archibald was asked to prepare an article for the MONTHLY giving a full description of this notable work by Chancellor Chace.

The Chauvenet prize for mathematical exposition, which was proposed by President Coolidge last spring, was formally adopted and the first award will be made at the annual meeting in Kansas City. A full description of the details of the prize has already appeared in the MONTHLY.

H. E. SLAUGHT, *Acting Secretary.*

THE MAY MEETING OF THE MARYLAND-VIRGINIA-DISTRICT OF COLUMBIA SECTION

The seventeenth regular meeting of the Maryland-Virginia-District of Columbia Section was held in McDowell Hall, St. John's College, Annapolis, Md., on May 16, 1925. There were two sessions, Professor F. D. Murnaghan being the chairman at each session. The attendance was thirty-two including the following twenty-six members of the Association: O. S. Adams, Sarah Beall, W. W. Bigelow, G. A. Bingley, C. C. Bramble, J. A. Bullard, Paul Capron, G. R. Clements, A. Cohen, A. Dillingham, Jessie B. Edmondson, H. English, D. M. Garrison, Alice A. Grant, H. Gwinner, W. M. Hamilton, W. D. Lambert, E. S. Mayer, F. D. Murnaghan, C. A. Nelson, B. C. Patterson, R. E. Root, J. B. Scarborough, W. F. Shenton, J. Tyler, E. W. Woolard. Those in attendance were guests at the luncheon given by the Annapolis members, and were given an address of welcome by the President of St. John's College.

The report of the nominating committee, Mr. English and Mr. Bramble, for officers for the next year was unanimously adopted and was as follows: Chairman, W. D. LAMBERT; Secretary-treasurer, J. A. BULLARD; State representatives, C. A. NELSON and T. McN. SIMPSON, Jr. The next meeting will be in Washington, D. C., probably in December.

The following seven papers were read:

(1) "The compression of a gravitating sphere," by Mr. W. D. LAMBERT, U. S. Coast and Geodetic Survey.

(2) "Some formulae connected with great circle sailing," by Mr. W. M. HAMILTON, U. S. Naval Observatory.

(3) "The accuracy of Simpson's rule" by Professor J. B. SCARBOROUGH, U. S. Naval Academy.

(4) "The identification of stars" by Miss SARAH BEALL, U. S. Coast and Geodetic Survey.

(5) "Some mathematical problems of meteorology" by Mr. E. W. WOOLARD, U. S. Weather Bureau.

(6) "The Neuberg cubic," by Mr. B. C. PATTERSON, Johns Hopkins University.

(7) "Some cissoidal curves," Dr. C. A. NELSON, Johns Hopkins University.

There were lively discussions of all papers, especially of that on the accuracy of Simpson's rule. Abstracts of some of the papers follow below, the numbers corresponding to the numbers in the list of titles.

1. Mr. Lambert's paper on the compression of a gravitating sphere brought out the difference between a gravitating and a non-gravitating fluid sphere, when uniform pressure is applied to the outer surface. This problem, which can be treated by comparatively elementary means, illustrates some of the difficulties encountered in the problem of the elastic deformation of a gravitating body as large as the earth, such a body being already in a state of internal stress under its own gravitation. If the modulus of compressibility of the earth is such as may be deduced from Laplace's law of density, a pressure of one atmosphere will shorten the radius by 2.91 meters if gravitation be considered, but only by 1.95 meters if it is neglected. The radial contraction in the more general case of any radially symmetrical distribution of density and compressibility may be found by solving a differential equation of the second order.

The gravitational energy evoked by such a radial contraction far exceeds the energy due to ordinary elastic strain. In the case considered, the former is 0.787×10^{33} ergs, in the latter 1.26×10^{27} ergs, a ratio of 600,000 : 1. If this gravitational energy were turned into heat, the resulting expansion would tend to diminish the radial shortening, which accordingly would attain the calculated value given above only when the heat had been radiated away, a process which, at the observed rate of radiation from the earth, would require 70,000 years. There would thus arise a distinction having some analogies to that between isothermal and adiabatic compression. The differential equation for the radial shortening in the "adiabatic" case contains additional terms depending on the specific heat and the coefficient of thermal expansion.

4. Miss Beall discussed the use of the astronomical globe and the stereographic projection for star identification and star spotting. The astronomical globe has been used by the Coast and Geodetic Survey since 1917 with great success. The stereographic projection for the use of the navigator is a great advance over star identification tables. Stars may be quickly identified, or observing lists may be prepared enabling the observer to get a star in the telescope of the sextant before it can be seen with the naked eye. This insures an observation while the horizon is well defined. The number of stars which may be used is extended and the use of the stars is made more attractive.

5. Given an urn in which there are n balls, of which a_1 are marked with the number x_1, a_2 with the number x_2, and so on to x_s. If we draw a ball at random, note the number, return the ball to the urn, and draw another, and so on, we obtain a sequence of numbers in random order. Suppose we take the absolute difference between each number in the series and the next following number; what, in the long run, will be the arithmetic mean of these differences?

In this paper, a formula for this mean value is derived, and its accuracy verified by experimental tests. The problem arose in connection with the statistical treatment of meteorological data; and the solution is designed to afford a means of testing time series to ascertain whether or not the variable quantity is taking on its values at random, such information frequently being of importance in deciding whether or not certain statistical formulae may be validly applied to the given data. The work is an extension of that of Goutereau and Maillet, who, in 1906, showed that in a random series drawn from a Gaussian distribution the ratio of the above mean to the mean deviation is equal to $\sqrt{2}$; mean daily temperatures, *e. g.*, show a Gaussian distribution, but the ratio mentioned is in general only about half $\sqrt{2}$, since the mean temperatures of consecutive days are not independent of one another. This paper has been published in full in the *Monthly Weather Review*, March, 1925.

7. Dr. Nelson put the Zahradruk construction for a rational plane cubic in projective form and gave a geometric characterization of the generating line and conic.

HARRY ENGLISH, *Secretary-Treasurer.*

ON CERTAIN APPLICATIONS OF THE DIFFERENTIAL AND INTEGRAL CALCULUS IN ACTUARIAL SCIENCE[1]

By H. L. RIETZ, University of Iowa

1. Introduction. The position which the Mathematical Association of America should take in the development of a broader and deeper interest in

[1] Presidential address delivered before the Mathematical Association of America, September 9, 1925.

applied mathematics has been emphasized by both Professor Hedrick and Professor Huntington in their retiring presidential addresses. In line with the general character of their suggestions, I shall attempt to bring to your attention certain applications of the calculus in actuarial science.

We may no doubt take it for granted as a general proposition that teachers of mathematics are looking over many fields for a wider range of applications with which to enrich their courses of instruction. This fact might perhaps be regarded as a sufficient reason for presenting a paper dealing with applications even from a field in which relatively few members of the Association have had a special interest. However, the speaker was moved mainly in the preparation of the present paper by the following somewhat more specific consideration: the teaching of certain very elementary parts of life insurance mathematics has grown so rapidly in recent years in connection with courses in the mathematics of finance that it seems not unlikely that a fairly large number of teachers would be interested in a simple exposition of the connection of the calculus with certain actuarial problems. It is with a feeling that you may be thus interested that I venture to take up your time by bringing to your attention applications from a field that is considerably removed from the most common source of applications—the physical sciences.

The time at my disposal will permit me to deal only with a certain class of very direct applications. It will not permit me to dwell upon the somewhat indirect applications of the calculus such as are involved in the development of interpolation, graduation, and quadrature formulas which are applied in the determination of mortality rates from statistical data, or in the approximate summation of the series which arise in actuarial science. To be more specific about the contents of the present paper my purpose in this address will be limited to bringing to your attention a few of the applications of the calculus to the theory and practice of life contingencies by assuming a continuous function to represent the law of mortality. Such applications have led to great improvements in actuarial theory which center around the ideas of continuous flow of population, continuous annuities, and assurances payable at the moment of death.

2. The representation of the law of mortality by a continuous function. On the basis of certain observations of the Halley tables (constructed in 1693) DeMoivre in his *Annuities on Lives*, published in 1725, put forth his well-known hypothesis that the decrement d_x per year in the number living l_x at age x is a constant for all values of x. This hypothesis is, of course, equivalent to an assumption that the number living l_x is given by a linear function of x within the age interval in question. It is doubtful whether much significance was attached by DeMoivre to the continuity of the function. In 1765, J. H.

Lambert[1] proposed a continuous function in the form of a polynomial of the fifth degree to represent the number living. Other formulas involving a combination of integral and exponential functions were proposed by Lambert and Duvillard.[2] These functions were simply in the nature of empirical formulas and it is again doubtful whether special use was made of the continuity properties of the function employed except for interpolation. But in 1825, B. Gompertz[3] not only introduced the continuous function $l_x = kg^{c^x}$ on a priori grounds to represent the number living for a certain range of ages, but he made use of the property of continuity of the function in defining what is sometimes called the instantaneous rate of mortality. He called this function the intensity of mortality and it is now commonly called the force of mortality by English and American actuaries. This step really gave the derivative of the function l_x and the corresponding force of mortality a place of fundamental importance in actuarial theory. The practical importance of Makeham's[4] first modification of the law of Gompertz, particularly in joint life insurance, has undoubtedly tended to increase the significance attached to the force of mortality and to the use of continuous functions in the treatment of life contingencies. Gauss, G. F. Hardy, Lazarus, Thiele, Dormey, Laurent, Wittsein, Quiquet, and other mathematicians and actuaries have proposed various formulas in the nature of continuous functions to represent mortality functions within certain age intervals. For an interesting discussion of such formulas, let me refer you to a recent paper by James S. Elston[5] on a "Survey of mathematical formulas that have been used to express a law of mortality." Most of these functions contain too many parameters to be convenient for practical purposes. However, the Makeham and the Wittstein[6] formulas contain a relatively small number of parameters and the latter may be regarded as of special interest in relation to the present paper because the number living l_x is expressed by means of an integral, and the maximal and minimal values of the probability q_x that a person aged x will die within a year are easily found by the use of the derivative dq_x/dx.

3. Certain elementary mortality functions involving derivatives and integrals. As a setting for our later remarks it seems desirable to introduce at this point a few very elementary mortality functions expressed in terms of

[1] *Beiträge, Zum Gebrauche der Mathematik und deren Anwendung* (1765).

[2] *Recherches sur les rentes, les emprunts et les remboursements* (1788).

[3] *Phil. Trans.* London, 115 (1825), pp. 513-583.

[4] *Journal of the Institute of Actuaries*, vol. 8, (1860), pp. 301-310, vol. 13, (1867), pp. 325-358; vol. 28, (1890), pp. 152-159; pp. 185-192; pp. 316-331.

[5] *Record of American Institute of Actuaries*, vol. 12, (1923), pp. 66-95. See also Quiquet, "Représentation algèbrique des tables de survie"; *Bulletin de L'Institute des Actuaries Français*, vol. III, no. 14, (1893).

[6] *Loc. cit.*, p. 82.

derivatives and integrals. First of all, assuming that the continuous function l_x has a derivative with regard to x at a given point, we define

$$\mu_x = -\frac{1}{l_x}\cdot\frac{dl_x}{dx} = -\frac{d\log_e l_x}{dx} \tag{1}$$

as the force of mortality at age x. In other words, the force of mortality at any age is the rate of change of the number living per person living at the given age.

Then the probability that[1] (x) will die in the age interval between $x+t$ and $x+t+dt$ is given to within infinitesimals of higher order by

$$-\frac{1}{l_x}\cdot\frac{dl_{x+t}}{dt}dt = \mu_{x+t}\frac{l_{x+t}}{l_x}dt = {}_tp_x\mu_{x+t}dt\ , \tag{2}$$

where ${}_tp_x$ is the probability that (x) will live t years. From (2) we have for the probability ${}_n|{}_mQ_x$ that (x) will die between ages $x+n$ and $x+n+m$

$${}_n|{}_mQ_x = -\frac{1}{l_x}\int_n^{n+m}\frac{dl_{x+t}}{dt}dt = \frac{l_{x+n}-l_{x+n+m}}{l_x}\ . \tag{3}$$

Given

$$\mu_{x+t} = -\frac{d\log_e l_{x+t}}{dt}\ ,$$

we have

$$-\int_0^t \mu_{x+t}dt = \log_e\frac{l_{x+t}}{l_x} = \log_e {}_tp_x \quad \text{or} \quad {}_tp_x = e^{-\int_0^t \mu_{x+t}dt}\ . \tag{4}$$

The force of mortality of joint lives, say of (x), (y), (z) at a time t from the present date may be defined by

$$\begin{aligned}\mu_{x+t:\,y+t:\,z+t} &= -\frac{1}{l_{x+t}l_{y+t}l_{z+t}}\ \frac{d\,(l_{x+t}l_{y+t}l_{z+t})}{dt} = -\frac{d}{dt}\log(l_{x+t}l_{y+t}l_{z+t}) \\ &= -\frac{1}{l_{x+t}}\cdot\frac{dl_{x+t}}{dt} - \frac{1}{l_{y+t}}\cdot\frac{dl_{y+t}}{dt} - \frac{1}{l_{z+t}}\cdot\frac{dl_{z+t}}{dt} = \mu_{x+t}+\mu_{y+t}+\mu_{z+t}\ .\end{aligned} \tag{5}$$

That is, the force of mortality for any number of joint lives is equal to the sum of the forces of mortality of the separate lives. The number living between ages x and $x+1$ at any moment is given by

$$L_x = \int_0^1 l_{x+t}dt\ . \tag{6}$$

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[1] The symbol (x) is used as an abbreviation for "a person aged x."

Then

$$\frac{dL_x}{dx} = \int_0^1 \frac{dl_{x+t}}{dt}\, dt = l_{x+1} - l_x = -d_x . \tag{7}$$

The central death rate m_x is defined by

$$m_x = \frac{d_x}{L_x} = -\frac{1}{L_x}\,\frac{dL_x}{dx} . \tag{8}$$

The complete expectation of life is defined by

$$\mathring{e}_x = \int_0^\omega {}_tp_x\, dt , \tag{9}$$

where ω is used to denote the upper bound of age and is sometimes written as ∞.

We might easily continue the list of mortality functions represented by means of derivatives and integrals, but those given will perhaps indicate the general nature of this representation, and serve our purposes in the present paper.

4. Continuous annuities. The payments under an annuity of annual rent 1 may be assumed to become more and more frequent so that the interval between two successive payments approaches zero as a limiting value. In the limiting situation, the annuity is called a continuous annuity.

The introduction of continuous functions in a systematic manner for the development of the theory of annuities and assurance should be attributed to W. S. B. Woolhouse,[1] in a paper published in 1869 "On an improved theory of annuities and assurances." The most elementary theory of life annuities is ordinarily based on annual payments. In the introduction to this paper, Woolhouse remarks that "it cannot but appear to be remarkable that the investigation of so elementary a value as that of an annuity, when diverted from its usual course and made payable half-yearly or quarterly, should not have been determined with greater accuracy in works on annuities and assurances. This may in some measure be ascribed to a sort of vague impression that a rough approximation might be considered sufficient for the cases which may be expected to arise in the course of actua' business. But, looking at the formidable character of some of the investigations, there can be but little doubt that a more potent reason is to be traced to the mathematical difficulty encountered in previous efforts to arrive at anything like an accurate formula, which would at the same time be sufficiently simple for the ordinary routine

[1] *Journal of the Institute of Actuaries*, vol. 15, (1869), pp. 95-195.

of office calculation." According to the principles laid down in the improved theory of Woolhouse, the number of lives, instead of being subjected to successive yearly decrements are considered to be decreasing continuously. As advantages of the new method, Woolhouse points out that it is with this method no longer necessary to be dependent on the gratuitous assumption that deaths which take place in any year are uniformly distributed throughout the year, and that the new method is not only more accurate in principle, and in all respects philosophically consistent, but that the various formulas are ordinarily simple and commodious for calculation.

The present value of the continuous life annuity of annual rent 1 for (x) is given by

$$\bar{a}_x=\frac{1}{l_x}\int_0^\omega l_{x+t}v^t dt=\int_0^\omega {}_tp_x\, e^{-\delta t}\, dt\,, \tag{10}$$

where $v=1/1+i$ is the discount factor, i being the interest rate, $\delta=\log_e(1+i)$ is the force of interest, and ω is the upper bound of age. Similarly, for a joint life annuity for n persons (x_1), (x_2), . . . (x_n), we have

$$\bar{a}_{x_1x_2\,..\,x_n}=\int_0^\omega {}_tp_{x_1x_2\,..\,x_n}\, e^{-\delta t}dt\,. \tag{11}$$

Different methods of evaluating this integral would be used according as the mortality table does or does not follow Makeham's first modification of the law of Gompertz.

A. When the mortality table follows Makeham's law. If the mortality table on which the annuity is based is given by Makeham's first modification of the law of Gompertz, that is, if

$$l_{x+t}=ks^{x+t}g^{c^{x+t}}\,,$$

then

$$\bar{a}_x=\int_0^\omega s^t e^{-\delta t}\, g^{c^x(c^t-1)}dt. \tag{12}$$

Let[1] $\qquad e^{-\delta}s=e^{-a}, \qquad g^{c^x}=e^{-q}$

Then (12) becomes

$$\bar{a}_x=\int_0^\omega e^{-at}\, e^{-q(c^t-1)}dt\,. \tag{13}$$

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[1] Cf. Insolera, *Corso di Matematica Finanziaria* (1923), p. 400.

Next, let $qc^t = y$, and $\alpha/\log c = p_1$ then (13) becomes

$$\bar{a}_x = \frac{e^q q^{p_1}}{\log c} \int_q^\infty y^{-p_1-1} e^{-y}\, dy . \tag{14}$$

Integration of (14) by parts gives

$$\bar{a}_x = \frac{1}{p_1 \log c}\left[1 - e^q q^{p_1} \int_q^\infty y^{-p_1} e^{-y}\, dy\right] . \tag{15}$$

In (15),

$$\int_q^\infty y^{-p_1} e^{-y}\, dy = \int_0^\infty y^{-p_1} e^{-y}\, dy - \int_0^q y^{-p_1} e^{-y}\, dy .$$

$$= \Gamma(1-p_1) - \int_0^q {}^{-p_1} e^{-y}\, y dy . \tag{16}$$

From (15) and (16), we have

$$\bar{a}_x = \frac{1}{p_1 \log c}\left[1 - e^q q^{p_1}\left\{\Gamma(1-p_1) - \int_0^q y^{-p_1} e^{-y}\, dy\right\}\right] . \tag{17}$$

Hence, we have $\bar{a}_x$ expressed in terms of a gamma-function and an incomplete gamma-function.

But for ordinary rates of interest, p_1 is likely to be a number between 0 and 1, and the Pearson tables[1] of the incomplete gamma-function would be directly applicable only when the exponent of y is positive. By further integration by parts, we obtain instead of (17),

$$\bar{a}_x = \frac{1}{\alpha}\left[1 - e^q q^{p_1}\Gamma(1-p_1) + \frac{q}{1-p_1} + \frac{e^q q^{p_1}}{1-p_1} \int_0^q y^{1-p_1} e^y\, dy \right] . \tag{18}$$

By the use of tables of gamma-functions and of incomplete gamma-functions, we now readily compute the continuous life annuity $\bar{a}_x$. The method is capable of immediate extension to joint life annuities. One of my recent graduate students—Mr. J. Van S. Longenecker of the Equitable Life Insurance Company of Iowa—tested this method of finding both single and joint life annuities by the use of the incomplete gamma-functions in (18) against the usual method of summation formulas such as the Woolhouse, Lubbock, Hardy and Weddle formulas. The test consisted in actually computing annuities for ages well distributed, and for several of the best known tables of mortality. Mr. Longenecker arrived at the conclusion from this fairly extensive study

[1] Karl Pearson, *Tables of the Incomplete Gamma-function*, 1922.

that both from the standpoints of accuracy and facility in calculation, the method of the incomplete gamma-functions is preferable to the other methods. So far as I have been able to learn the use of the incomplete gamma-functions to compute annuities is new, but Emory McClintock made use of the ordinary gamma-function for this purpose as early as 1874. In 1873 W. M. Makeham[1] expressed the continuous annuity $\bar{a}_x$, based on a mortality table given by his first modification of the law of Gompertz, in a form which involved no difficulties except such as are involved in an integral of the form

$$\frac{1}{\log}\ \frac{1}{10^{-10^x}\ e^{-nz}}\ \int_x^\infty 10^{-10^x} e^{-nz} dz.$$

He then prepared a double entry table of

$$\log \frac{1}{10^{-10^x}\ e^{-nz}}\ \int_x^\infty 10^{-10^x} e^{-nz} dz$$

with respect to the arguments n and z for the calculation of continuous annuities. In 1874, Emory McClintock[2] published a rival method of calculation of the continuous annuities for which he held he could obtain the same results as by Makeham's method and without any other table than that of the ordinary gamma-function. His method involved the expansion of an integral of the form

$$\int_v^\infty e^{-v} v^r dv$$

in a series the first term of which involved the gamma-function. The slow convergence of the series makes this method of little value in many cases of joint life assurance and even in some cases for an annuity on a single life.

On the other hand, by the use of the Pearson tables of the incomplete gamma-function it seems fairly well established that we have now a simpler and more satisfactory method than has previously been known for the calculation of annuities based on a Makehamized table and at a rate of interest for which auxiliary tables such as commutation columns have not been calculated.

B. When the mortality table does not follow Makeham's law. The general theory of continuous annuities dating from the fundamental paper of Woolhouse is not dependent upon the use of a Makehamized mortality table. Thus, we write for the continuous annuity as in (10),

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[1] *Journal of the Institute of Actuaries*, vol. 17, (1873), pp. 306-327.

[2] *Journal of the Institute of Actuaries*, vol. 18, (1874), pp. 242-251.

$$\bar{a}_x=\frac{1}{l_x}\int_0^\omega v^t l_{x+t}dt\ . \tag{19}$$

From (19), by making $v^{x+t}l_{x+t}=D_{x+t}$, we have

$$\bar{a}_x=\frac{1}{D_x}\int_0^\omega D_{x+t}dt\ . \tag{20}$$

If the object is to express the continuous annuity $\bar{a}_x$ in terms of an ordinary life annuity a_x and certain correctional terms, we may ordinarily simply use the Euler-Maclaurin formula and obtain from (20)

$$\begin{aligned}\bar{a}_x&=\frac{1}{D_x}\left\{\sum_{t=1}^{t=\omega}D_{x+t}+\tfrac{1}{2}D_x+\frac{1}{12}\ \frac{dD_x}{dx}+\cdots\cdot\right\}\\&=a_x+\frac{1}{2}-\frac{1}{12}(\mu_x+\delta)\ \text{approx.}\end{aligned} \tag{21}$$

On the other hand, suppose the present value of the ordinary annuity is not available, and that we wish to obtain such value on the basis of a mortality table for which auxiliary functions are not available. To do this we proceed to the valuation of an integral such as (19), by the use of some quadrature formula. Actuaries have found one of G. F. Hardy's summation formulas,[1] the famous formula (39a), particularly convenient for such annuity calculations. By such approximate valuation of the integral in (19), we have a convenient method of finding the present value of an ordinary life annuity based on a mortality table or rate of interest for which auxiliary tables are not available. This method of finding the value of annuities is found particularly useful in the case of joint life and survivorship annuities.

5. Assurance payable at the moment of death. It is common practice to define the net premium for life assurance on the hypothesis that the claim is to be paid at the end of the policy year in which death occurs; but as a matter of business practice, the claim is paid as nearly the instant of death as is possible. Thus, a theory of assurance payable at the instant of death conforms much more closely to actual practice than a theory based on the commonly accepted hypothesis that claims are paid at the ends of the policy years.

Since the probability that (x) will die at an age between $x+t$ and $x+t+dt$ is to within infinitesimals of higher order

$$-\frac{1}{l_x}\cdot\frac{dl_{x+t}}{dt}\,dt\ ,$$

[1] *Text-book of the Institute of Actuaries*, (1902), p. 488.

it follows that the value of a whole life assurance of 1 payable at the moment of death of (x) is

$$\bar{A}_x = -\frac{1}{l_x}\int_0^\omega v^t \frac{dl_{x+t}}{dt}\,dt \tag{22}$$

$$= 1-\delta\bar{a}_x\,, \tag{23}$$

as may be shown by integration by parts where $\bar{a}_x$ is the present value of a continuous life annuity of annual rent 1.

Thus, the single premiums for a temporary or for a whole life assurance are given very simply in terms of the corresponding continuous annuities.

6. Contingent probabilities of life. A comparison of the new book (1922) of the Institute of Actuaries on *Life Contingencies* by E. F. Spurgeon with the classic text-book by George King shows particularly the improvement in the presentation of contingent probabilities by the more extensive use of the differential and integral calculus. The older treatment involved cumbersome approximations dependent on the assumption of the uniform distribution of deaths throughout the year, and corrections for errors growing out of this assumption. These approximations have been eliminated, to a considerable extent, and a more elegant treatment substituted by the use of the calculus. The application of the calculus in this connection can perhaps be seen with sufficient clearness for our purposes by considering a few examples involving two and three lives.

A. Two lives. Let us find the probability that (x) will die in the $(n+1)$th year from the present time, (y) being alive at the moment of death of (x).

The probability that (x) will die at an *age* between $x+t$ and $x+t+dt$, (y) being alive at age $y+t$ is, to within infinitesimals of higher order,

$$-{}_tp_y\frac{dl_{x+t}}{l_x} = {}_tp_x\ \mu_{x+t}\ {}_tp_y\,dt = {}_tp_{xy}\,\mu_{x+t}\,dt\,, \tag{24}$$

where ${}_tp_{xy}$ is the probability that both (x) and (y) will live t years.

This expression integrated from $t=n$ to $t=n+1$ is the probability ${}_n|\,q^1_{xy}$ that (x) will die before (y) in the $(n+1)$th year. That is,

$${}_n|q^1_{xy} = \int_n^{n+1} {}_tp_{xy}\,\mu_{x+t}\,dt\,. \tag{25}$$

Similarly, the probability that (x) will die before (y) within n years is

$$|_nQ^1_{xy} = \int_0^n {}_tp_{xy}\,\mu_{x+t}\,dt\,. \tag{26}$$

B. Three lives. The probability Q^1_{xyz} that of three lives (x), (y), and (z), (x) will die first is

$$Q_{\frac{1}{xyz}} = \int_0^\omega {}_tp_{xyz}\,\mu_{x+t}\,dt\,, \tag{27}$$

where ${}_tp_{xyz}$ is the probability that (x), (y), and (z) will each live t years.

As another example, the probability that (x) will die third of three lives (x), (y), and (z) is

$$\begin{aligned} Q_{\frac{3}{xyz}} &= \int_0^\omega (1-{}_tp_y)(1-{}_tp_z)\,{}_tp_x\mu_{x+t}dt \\ &= \int_0^\omega (1-{}_tp_y-{}_tp_z+{}_tp_{yz})\,{}_tp_x\mu_{x+t}dt = 1-Q_{\frac{1}{xy}}-Q_{\frac{1}{xz}}+Q_{\frac{1}{xyz}} \end{aligned} \tag{28}$$

where $\frac{1}{x}$ indicates that (x) is to die first.

The numerical valuation of the integrals giving such contingent probabilities of life is usually accomplished by approximate integration, although this would not necessarily be the case if the mortality table follows a formula such as that of Makeham.

7. Joint life assurances. The present value of 1 payable at a time between t and $t+dt$ years from the present if the joint existence of a set of lives, say (x), (y), and (z) fails at that time is, to within infinitesimals of higher order,

$$-\frac{v^t}{l_x l_y l_z}\,\frac{d(l_{x+t}l_{y+t}l_{z+t})}{dt}\,dt = v^t\,{}_tp_{xyz}\,\mu_{x+t:\,y+t:\,z+t}\,dt \tag{29}$$

and the value of a joint life assurance of 1 payable at the moment of the first death among these lives,

$$\bar{A}_{xyz} = \int_0^\omega v^t\,{}_tp_{xyz}\,\mu_{x+t:\,y+t:\,z+t}\,dt \tag{30}$$

$$= \int_0^\omega v^t\,{}_tp_{xyz}\,(\mu_{x+t}+\mu_{y+t}+\mu_{z+t})\,dt \tag{31}$$

by formula (5).

It may be observed that the integral (30) giving the continuous joint life assurance may be formed from the integral (11) for the corresponding continuous joint life annuity by multiplying the integrand in (11) by the force of mortality of the set of lives involved.

8. Contingent life assurances. In its simplest form, a contingent life assurance involving only two lives provides for the payment of 1 on the death of (x) known as the "failing" life provided (y) known as the "counter" life should survive him.

The value 1 payable at time t from the present if (x) die between ages $x+t-dt$ and $x+t$, (y) surviving him, is to within infinitesimals of higher order

$$v^t {}_tp_{xy}\, \mu_{x+t}\, dt\ ,$$

and the total value of such an assurance for the whole of life, payable at the moment of death of (x), provided (y) survive him is

$$\bar{A}^{1}_{xy} = \int_0^{\omega} v^t {}_tp_{xy}\, \mu_{x+t}\, dt\ , \tag{32}$$

where ω is the upper bound of age. It may be observed that this integral for a contingent assurance payable on the death of (x) may be obtained from the integral for a continuous joint life annuity to (x) and (y) by multiplying the integrand by the force of mortality of the "failing" life at age $x+t$.

Contingent life assurance may be payable in some other way than on the first death, and these cases also lend themselves to treatment by the means of definite integrals. For example, the value $\bar{A}^{2}_{xy}$ of an insurance of 1 payable at the moment of death of (x) if he die after (y) is

$$\bar{A}^{2}_{xy} = \int_0^{\omega} v^t(1-{}_tp_y)\,{}_tp_x\mu_{x+t}dt = \bar{A}_x - \bar{A}^{1}_{xy} \tag{33}$$

which is equal to an assurance of 1 payable on the death of (x) diminished by an assurance payable on the death of (x) if he die before (y).

9. Reversionary annuities. A continuous reversionary annuity $\bar{a}_{y|x}$ to (x) after (y) is an annuity to begin on the death of (y) and to continue thereafter during the life of (x). Such an annuity may be expressed as an integral in the following form:

$$\bar{a}_{y|x} = \int_0^{\omega} v^t(1-{}_tp_y)\,{}_tp_x dt \tag{34}$$

$$= \bar{a}_x - \bar{a}_{xy}\ . \tag{35}$$

The increased tendency to apply the calculus in dealing with reversionary annuities is shown by the fact that in the text-book of the Institute of Actuaries last revised in 1902, the integral sign appears only on the last two pages of the fourteen pages devoted to reversionary annuities whereas in the corresponding recent book of the Institute by Spurgeon published in 1922, the integral sign

appears on the first page and the calculus plays an important role throughout the entire chapter of twenty pages.

10. Compound survivorship annuities. In the ordinary reversionary annuity, payable to (x) after the deaths of (y) and (z), no specification is made as to the order of deaths of (y) and (z).

But assume an annuity payment to (x) after the failure of the joint lives (y) and (z) by the death of (z). Then we have a condition of compound survivorship. If both (x) and (y) are living at the moment of death of (z), (x) enters into possession of a continuous life annuity. Denote such an annuity by $\bar{a}_{yz|x}$. Then

$$\bar{a}_{\underset{yz|x}{1}} = \int_0^\infty v^t \, {}_tp_{xyz}\mu_{x+t}\bar{a}_{x+t}dt \,. \tag{36}$$

This function $\bar{a}_{yz|x}$ has attracted much attention relative to its commercial importance. The actuary is very generally seeking for formulas amenable to calculation. Ordinarily he would resort to approximate summation when numerical results are needed from such a formula as (36), but in 1895, F. E. Colenso published a paper[1] which included the reduction of (36) to a form suitable for direct numerical calculation when the mortality table follows Makeham's first modification of the law of Gompertz.

We have commented on the relatively small commercial importance of compound survivorship annuities. With the extension of the inheritance taxes which may be levied severely on successive interests we may find increased applications of compound survivorship annuities. That is to say, such taxation may result in proposals that insurance companies go much further with survivorship annuities than has hitherto been the rule.

11. On the relation between assurance functions based on two different mortality tables. When we take account of the laborious calculations involved in the preparation of appropriate commutation columns, valuation functions, pure endowment functions, forborne immediate annuity functions, and other actuarial functions which accompany certain mortality tables which are much used in assurance practice, we appreciate the importance of any contribution to the solution of the problem of expressing assurance functions based on a mortality table for which the numerical values of the auxiliary actuarial functions are not available in terms of available functions of a standard mortality table.

Among the applications of the calculus to be considered in the present paper, it seems fitting to direct attention to a method of calculation of assurance func-

[1] *Jour. Institute of Actuaries*, vol. 31, pp. 337-56.

tions based on any mortality table that follows Makeham's law, and at an arbitrary rate of interest, by means of available tables based on a standard Makehamized mortality table at various rates of interest.

In 1904, the eminent Danish actuary, Dr. J. P. Gram, published a paper[1] dealing with this problem.

A brief exposition of the method developed by Gram was given by Christian Jensen in a paper[2] in the *Transactions of the Actuarial Society of America*, in 1908.

Given the force of mortality $\mu_x = \alpha + \beta e^{\gamma x}$ of a standard table and

$$\mu_x' = \alpha' + \beta' e^{\gamma' x}$$

of a special table on which we wish to base our calculations. The method of obtaining the assurance functions of the special table rests on showing that

$$\mu_x' = \rho + \mu_{\lambda x + \epsilon}, \tag{37}$$

where

$$\rho = \alpha' - \alpha\,, \qquad \epsilon = \frac{\log_e \beta' - \log_e \beta}{\gamma}\,, \qquad \lambda = \frac{\gamma'}{\gamma}\,.$$

We observe from (37) that we may use a force of mortality from a standard table transformed by (*a*) multiplication of the age by a constant, (*b*) addition of a constant to the thus transformed age, (*c*) addition of a constant ρ to such force of mortality.

It may now be readily shown that a continuous temporary life annuity $\bar{a}'_{x\overline{n}|}$ based on our special mortality table is given in terms of a corresponding continuous annuity $\bar{a}_{z\overline{m}|}$ on a standard table by

$$\bar{a}'_{x\overline{n}|} = \frac{1}{\lambda}\bar{a}_{z\overline{m}|}\,,$$

where

$$z = \lambda x + \xi\,, \qquad \xi = \frac{\log_{10}\dfrac{\beta'}{\lambda\beta}}{\gamma \log_{10} e}\,, \quad m = \lambda n\,, \quad \text{and } \delta + \alpha = \frac{\alpha' + \delta}{\lambda}\,,$$

where δ and δ' are forces of interest.

The relation $\alpha + \delta = (\alpha' + \delta')/\lambda$ gives the required value of δ since the remaining symbols are assumed to be known. If we have annuity tables based on our standard mortality table following Makeham's first modification of the law of Gompertz, and for a sufficient number of values of the interest rate for interpolation, then the annuity values for an assigned force of interest δ can be found by interpolation. The important conclusion in this connection is that

[1] *Skandinavisk Aktuarietidsskrift* (1904).

[2] Vol. 10, pp. 503-8.

we can calculate the annuity values based on our special mortality table following Makeham's law and an arbitrary rate of interest by means of interpolation for age and rate of interest and multiplication by a constant. The calculus is obviously involved throughout Gram's method which is based on forces of mortality.

12. The use of the calculus in the problem of the flow of population. In the applications of the calculus to which attention has thus far been directed in the present paper, we have assumed a law of mortality given by a continuous function l_x of the age. This assumption implies, on the numerically practical side, that we are basing our developments on a given table of mortality. For pedagogical reasons, it seems desirable to assume a table of mortality as a starting point in the teaching of actuarial theory. But it is fairly obvious that the more logical order would be to develop first the theory and methods of construction of mortality tables from statistical data. We find in recent methods of construction of such tables that very important use is made of the infinitesimal calculus in the theory of the flow of population which underlies the most elegant methods for the construction of life tables.

The development of the theory of the flow of population to which I refer centers around the names of Knapp, Zeuner, Lexis, Perozzo, and Blaschke. The work is most readily available to the American student through the excellent exposition of the theory given by James W. Glover under the title "Mathematical theory of construction of life tables" in his *United States Life Tables* (1921). Professor Glover deserves very much credit for the careful and useful work he has done in the exposition of the theory and its application to U. S. census data. In this theory, the aggregates of those living to the same age and of those living at the same time are represented by definite integrals. The function giving the number of deaths between ages x and $x+\xi$ satisfies a linear differential equation of the first order and degree with ξ as the independent variable. The solution of this differential equation gives the value of the number of deaths between ages x and $x+\xi$ in terms of the number E exposed and the force of mortality. This solution combined with the fundamental formula $q_x=1-e^{-\int_x^1 \mu_{x+\xi}\,d\xi}$ for the probability of death within a year enables us to compute tables of probabilities of death from statistical aggregates.

In conclusion, I think we may say that it is fairly obvious from the developments of actuarial theory in the past thirty years that the applications of the infinitesimal calculus in this field have tended to increase during this period both in the development of a more satisfactory theory for the construction of mortality tables and in the theory of life contingencies based on a given mortality table.

THE ARITHMETIC OF JEHAN ADAM, 1475 A.D.

By LYNN THORNDIKE, Columbia University

In a manuscript of the fifteenth century in the Bibliothèque Sainte Geneviève, Paris,[1] is an arithmetic in French. Both its text and author appear to have passed hitherto unnoted in works upon the history of mathematics. Yet it seems to contain an earlier example of numeration carried as far as trillions than has hitherto been recorded.[2] It was composed in the year 1475. As the introductory epistle at the beginning of the manuscript states, the author is Jehan Adam, who was secretary to Nicolle Tilhart, who in his turn was notary, secretary, and auditor of accounts to Louis XI, king of France from 1461 to 1483. That monarch more than once figures in the examples given in our text. Thus under Addition (fol. 9v) we are told, "le Roy donne a mons^{r} Lepaunatier IIII^{m}V^{c}XXIII (i. e. 4523), a mons^{r} Leschaconn II^{m}III^{c}XLI (2341), a mons^{r} Lesciuer III^{m}II^{c}XXIII (3223), a mons^{r} le maître doustel XIII^{c}XLII (1342). . ." ("The king gives Monsieur Lepaunatier 4523, M. Leschaconn 2341, M. Lesciver 3223, Master Doustel 1342"). Or in the first example of halving (*Mediacion*, at fol. 5r) we read, "The king gives the half of 51607 livres to Monsieur de Hourluum, that is, 25803 livres, ten sous."[3]

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[1] Ste. Geneviève MS Français 3143.

Since this article went to press Professor David Eugene Smith has called my attention to an item in the 1898 sales catalogue of the library of Prince Boncompagni which indicates that he had somehow come into possession of a recent copy or facsimile of the work of Jehan Adam. This copy was apparently made from our Sainte Geneviève MS., but the sales catalogue states that Boncompagni had asked Marre to search for the original MS. in the Bibliothèque Nationale and other libraries of Paris, and that he had failed to locate it. It is nevertheless duly listed in Ch. Kohler's *Catalogue des manuscrits de la Bibliothèque de Ste. Geneviève*, published in 1893. The following is the notice in the *Catalogo della Biblioteca Boncompagni*, Parte Prima, Roma, 1898, p. 94: "499. Adam Iehan. Traicté d'arismetique pour la pratique par gectouers (SIC) faite et compillé a Paris en lan mil 475, della Biobl. di 79 carte membranacee, salvo le prime due e le due ultime che sono cartacee. Scritto nel sec. xix. Facsimile, con grande accuratezza eseguito, con iniziali e figure a oro e colori e titoli rubricati. Il Princ. Boncompagni, avendo pregato il Sig. Marre di ricercare se l'originale del detto trattato di Jehan Adam si trovasse nella biblioteca Nazionale od in altra di Parigi, egli gli fece sapere che ogni ricerca in proposito riusci infruttuosa."

[2] The earliest example hitherto known appears to have been in the *Triparty* of Nicolas Chuquet, a bachelor of medicine in Paris, dated 1484 at Lyons.

See Aristide Marre, "Notice sur Nicolas Chuquet et son Triparty en la science des nombres" in Boncompagni's *Bullettino di Bibliografia e di Storia delle Scienze Matematiche e Fisiche*, Tomo XIII, 1880, pp. 555-592, followed at p. 593 *et seq.* by Chuquet's text. I owe this reference and other helpful suggestions to the kindness of Professor David Eugene Smith. Chuquet carried the nomenclature on beyond trillion and quadrillion to *nonyllion*, as the form is given in the printed text, or *nouyllion* (or, *novyllion*) as I read it in the facsimile of the manuscript (Paris, Bibliothèque Nationale, MS Français 1346; once Codex Colbert 2170, Regius 7483) in Professor Smith's library. Neither Chuquet nor his modern editor mentions the arithmetic of our Jehan Adam which is earlier by nine years.

[3] fol. 5r, "Mediacion est assavoir combien monte la moictie dun nombir proposi Exemple Le Roy donne la moitie de li^{m}vi^{c}vii l. (i. e. the sign for livres) a mons^{r} de hourluum cest xxv^{m} huic cens troys livres dix sols . . . ."

Our arithmetic is of the abacus type, reckoning by *jetons* or counters.[1] This word is commonly spelled *gectoners* in our manuscript,[2] but the form *greton* also occurs at least once.[3] Jehan Adam, however, although he still usually employs the Roman numerals, was acquainted with the Hindu-Arabic numerals. At fol. 9r he writes them out as far as 100, then by hundreds up to one thousand,[4] "2000, 8000,[5] etc. Et ainsi jusques infini en assemblent les nombres digitz articulz."

Our arithmetic is the only, or at least the chief, treatise in the manuscript, which is a small, illuminated codex with seventy-five leaves of text in all. The writing is in a fairly large hand, so that there is not very much text per page. The spelling of the old French is at times difficult to decipher. Illuminated figures to illustrate graphically the sums and calculations of the text also occupy some of the space. None occurs, however, between fol. 33r and fol. 60r inclusive. The manuscript has been incorrectly bound so that the leaf now numbered fol. 5r-v and devoted to the topics of Halving and Doubling should be transposed with the leaf now numbered fol. 13r-v, which continues the opening chapter of the text proper begun on fol. 4v. At fol. 63r this main body of text proper ends after three lines at the top of the page. Most of the page is then left blank until, near the bottom of the page, comes the rubric, "Conclusion et fin de ce present traicte en continuant lespitre escripte au commencement dicelluy." That is to say, the author here resumes the epistle with which he opened his work at fols. 1-4. His devout conclusion terminates at fol. 66r with the words, " . . . . a laquelle nous puissons tous venir a la reste de nos jours. Amen." This *Explicit*, as it would seem, is then followed at fols. 66v-69v by a table of contents. The manuscript, however, does not end

[1] See E. Littré, *Dictionnaire*, 1869; "Les jetons se réduisent à une échelle dont les puissances successives au lieu de se placer de droite à gauche comme dans l'arithmétique ordinaire se mettent du bas en haut chacune dans une ligne où il faut autant de jetons qu'il y a d'unités dans les coefficients." Littré cites Buffon, *Ess. arithm.*, (*Œuvres*, X, 781).

More recently the whole matter of these *jetons* or *jettons* has been the subject of elaborate treatment with handsome plates by Francis Pierrepont Barnard, *The Casting-Counter and the Counter-Board*, Oxford, Clarendon Press, 1916, 358 pp., lxiii Pl. For briefer accounts, with especial reference to early printed arithmetics and the history of mathematics see David Eugene Smith, *Computing Jetons*, The American Numismatic Society, New York, 1921; and the same author's recent *History of Mathematics*, 1924, vol. II, chapter 3.

[2] fol. 4r, "arismeticque pour la praticque par gectoners"; fol. 20v, Rubric, "Septiesme et dernier espece darismeticque par gectoners." Littré, *op. cit.*, cites De Laborde, *Emaux*, p. 328, for the form *gectons* in the fourteenth century, "Gectons de la chambre des comptes de Monseigneur le duc d'Orléans." *Gecton* also occurs among some fifty forms of the word in French which Professor Barnard lists at pp. 26-27 of his aforesaid work, but neither of our forms, *gectoners* or *greton*, is among them. Possibly in the two passages quoted *gectoners* may denote those who make use of the counters or *gectons*.

[3] fol. 7r, "Item noctes que le premier greton dembas vault ung."

[4] By a slip 600 is written twice.

[5] Our author employs the old characters, 8, 4, and ^, for four, five, and seven respectively.

there, but, with a "regle pour faire une taille de Monnoye," and further text and headings, goes on to fol. 75r. Perhaps these apparent additions should be transposed back into the text at some point.

Jehan Adam divides arithmetic into nine parts: numeration, addition, subtraction, halving, duplication, multiplication, division, progression, and extraction of roots.[1] He states, however, that in this present treatise he will treat of only seven of these parts, leaving progressions and the extraction of square and cube roots to another treatise.[2] Whether it is in existence or was ever written by him, I do not know. He is aware, moreover, that arithmetic may be subdivided differently. Thus Master Bartholomew of Roumanis (or Romains?), professor of Holy Scripture, makes but five parts of arithmetic, namely, addition, subtraction, multiplication, division, and extraction of roots. And it is true that halving is simply dividing by two, and that doubling is simply multiplying by two, while progression may be explained as addition. Division is of two sorts, "*simple et miste.*"[3]

The most interesting and novel feature of Jehan Adam's work is the paragraph and the illuminated figure in his section on Numeration which he devotes to the twenty decimal numbers from one to ten trillions (*dix trimillions*).[4] These are represented in the figure by as many counters (*jetons*), balls, or circles, superimposed one above another as if on an abacus, and with only one ball or counter for each denomination. Instead of "billion" Jehan writes *bymillion*, and instead of "trillion," *trimillion*.[5] He quotes the Latin verses of Alexander of Villa Dei[6] which enumerate up to ten figures (1,000,000,000), but then he goes on by himself to the twentieth figure or *dix trimillions* (10,000,000,000,000,000,000). Explaining the illumination, he says:

"Also note that the first counter from the bottom stands for one, the second stands for ten, the third stands for one hundred, the fourth stands for one thousand, the fifth stands for ten thousand, the sixth

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[1] fol. 13r, "Et est assavoir que en arismeticque sont ix especes Numeracion Addiction Substraction meditacion dupplacion Multiplicacion division progression Extraction de Radices.

[2] fol. 4r.

[3] fol. 21v. The treatment of simple division continues to fol. 28v; then follow mixed division and the rule of three. "En division mixte la regle de trois est la forme a laquelle toute subtille question se doit reduire tant per nombre houpt que autier (or, *aultre*)."

[4] The text occurs at fol. 7r; the illumination on fol. 7v.

[5] Chuquet, on the other hand, spells the words in question "byllion" and "tryllion."

[6] fol. 8v,

"Unum prima, secunda decem, dat tercia centum,
Quarta dabit mille, millia quinta decem,
Centum mille sexta dat, septima millia mille,
Mille dat octava millesies decies,
Centesies nova dat millesies quoque mille,
Millesies mille millesies decima,
Sic per millarium centenum denariumque."

These lines do not occur, however, in the version of the *Carmen de Algorismo* of Alexander of Villa Dei published in J. O. Halliwell's *Rara Mathematica*, 1841, pp. 73-83.

stands for one hundred thousand, the seventh stands for a million, the eighth stands for ten millions, the ninth stands for one hundred millions, the tenth stands for one thousand millions, the eleventh for ten thousand millions, the twelfth for one hundred thousand millions, the thirteenth for a billion, the fourteenth for ten billions, the fifteenth for a hundred (thousand)[1] billions, the sixteenth for a thousand billions, the seventeenth for ten thousand billions, the eighteenth for a hundred thousand billions, the nineteenth stands for a trillion, the twentieth for ten trillions."

Jehan Adam makes one or two brief incursions into the history of arithmetic. He has several suggestions to make as to the etymology of the word.[2] Arithmetic he derives from the Greek, *Ares*, meaning virtue, and from the Greek word for number. But the art is also called Algorismus from the Arabic, meaning an introduction to numbers, and this word may come from Algos, the name of the Arabic inventor of the art, and *Richmos*, a Chaldean word for number, or perhaps from the Greek *al*, equivalent to the Latin *in*, and *gogos*, equivalent to *dictio*. In another passage besides "the noble philosopher, Algus," (Jehan seems to have no preference as between the Latin and Greek forms of proper names) "the inventor and first compiler" of arithmetic, are listed Aristotle, Plato, Pythagoras, Isidore, Boethius, Albert, Alexander of Villa Dei, Masters Bartholomew des Roumanis, John of Sacrobosco, Johannes de Lineriis, Jean de Meun,[3] and Jehan Loquemeron, as past masters of the art.[4]

The problems of our arithmetic range from such simple ones as to multiply 2321 by xxiiii,[5] or, "If twelve ells of cloth are worth 34 livres, how much will 26 ells be worth,"[6] to more complicated problems concerning the division of profits among merchants forming a company and contributing different amounts of capital,[7] or even investing different sums for different periods of time,[8] or "touching a serpentine concerning which the King wants to know

[1] "cent mil bymillions" is evidently a slip for "cent bymillions." The French text of the passage reads: "item noctes que le premier greton dembas vault ung, le second vault (. . . . here some words seem to be omitted) cent, le quart vult mille, le Ve vault dix M, le VIe vault cent M, le VIIe vault Milion, Le VIIIe vault dix Million, Le IXe vault cent Millions, Le Xe vault Mil Millions, Le XIe vault dix mil Millions, Le XIIe vault Cent mil Millions, Le XIIIe vault bymillion, Le XIIIIe vault dix bymillions, Le XVe vault cent (mil) bymillions, Le XVIe vault mil bymillions, Le XVIIe vault dix Mil bymillions, Le XVIIIe vault cent mil bymillions, Le XIXe vault trimillion, Le XXe vault dix trimillions."

[2] fol. 4v.

[3] One might expect mention of John of Meurs (Johannes de Muris) rather than of the second author of *The Romance of the Rose* in a list of arithmeticians, but Iehan de Mehung seems unmistakably to denote the latter.

[4] fols. 2v—3r, "Et depuis Aristote platon pitagoras ysodore Boisse Alebert Alixandre de Villedieu Maistres bartholomieux des Roumanis Iehan de sacro bosco Iehan de Ligneriis Iehan de Mehung et Iehan Loquemeron en ont si bien oy (?) souverament traicte que nulle Reprehencion ny doit estre faicte."

[5] fol. 16v.

[6] fol. 30v.

[7] fol. 33v

[8] fol. 42v.

the quantity of each metal that will be in one of the broken pieces."[1] We also have "Rules" for over-charge and annulments (? *recindemens*),[2] for recovery of annulments,[3] for equal and mixed proportion,[4] for fractions[5]—as to divide a sum in ratios of 1/2, 1/3, and 1/4, or 1/3, 1/4, 1/5, and 1/6—and for alloying money.[6]

It is interesting to associate this arithmetic of Jehan Adam composed in 1475, with the important *Triparty* of Nicholas Chuquet,[7] finished in 1484. Both works were thus composed within a decade of each other, both were written in French and by authors intimately connected with Paris, and they are the first two works known to employ the terms, billion and trillion. There is another similarity and sign of close connection between them. The master Bartholomew, "des Romanis" or "des Roumanis," whom Jehan Adam mentioned at least twice, is also cited and a passage from his work criticized in the appendix to Chuquet's *Triparty*, where he is called "*maistre berthelemy de rōmans*, formerly of the Order of Friars Preachers at Valence and doctor in theology."[8] Similarly Jehan Adam spoke of him as "*professeur en la saincte escripture.*" What was the debt of our two authors to this Bartholomew and can his own work be recovered?

THE EARLY CONTRIBUTIONS OF CARL SCHOY[9]

By DAVID EUGENE SMITH, Columbia University

The recent appointment of Dr. Carl Schoy as "Lehrauftrag für Geschichte der exacten Naturwissenschaften im Orient" in the University of Frankfort am Main, the work beginning on October first of the current academic year, is so significant in the study of the history of mathematics as to deserve more than a mere passing notice. The number of scholars who are proficient not only in mathematics and astronomy but also in the eastern languages has always been limited, even as it is today. Woepcke, who began as a Privatdozent at

[1] fol. 41r.

[2] fol. 36r, Rubric, "Regle de trop charge et Recindemens."

[3] fol. 38v, Rubric, "Aultre Regle et maniere de Repprendre les Recindemens."

[4] fols. 44v-45r.

[5] fol. 46r *et seq.*

[6] fol. 59v, Rubric, "Regle pour aloyer monnoye avecques au lire monnoye."

[7] See note 1a above.

[8] Aristide Marre, "Appendice au Triparty en la science des nombres de Nicolas Chuquet Parisien," in Boncompagni's *Bulletino di Bibliografia e di Storia delle Scienze Matematiche e Fisiche*, Tomo XIV, (1881) pp. 415-16 and 442.

[9] See also in this connection a "Note on the mathematics of the Arabs" by Professor L. C. Karpinski published in the MONTHLY (1925), pp. 44-45.

Bonn was such as scholar, and so was Sédillot. The younger Hankel was unusually well qualified to undertake the interpretation of Arabic mathematics, but his early death prevented his work from progressing beyond the initial stages. Rosen, nearly a century ago, gave us a worthy translation of Al-Khowârizmî, and Braunmühl, at the close of the last century, contributed materially to our knowledge of Arabic trigonometry; but it was not until recently that men like Carra de Vaux and particularly the late Professor Suter brought modern scholarship to bear upon the problem of making the Arabic literature in mathematics better known to scholars of the present day. It was a century before a worthy successor to Colebrooke appeared in the person of the late Professor Rangacharya, and it is only now that scholars like Mikami and Père Vanhée are making known any considerable amount of the ancient mathematics of the Far East.

Within the last half dozen years a new name has been added to the list of scholars who have been or are able to interpret clearly the Mohammedan astronomy and mathematics, and his contributions have been such as to give confidence that he is destined to rank among the leaders in this field of science. Dr. Schoy was a student under Professor J. Chr. Seybold of Tübingen and was, in fact, his only one during the war period. With him he had a thorough training in the reading and interpretation of Arabic manuscripts, besides studying Persian and Turkish and devoting a considerable amount of time to mathematics and astronomy. From 1919 to 1921 he was Privatdozent at Bonn, his chief interests being in the field of mathematical geography and the history of geography and astronomy.

Since that time his output of work has been notable, including the following memoirs and volumes:

1920. "Das 20. Capitel der grossen Ḥākimitischen Tafeln des Ibn Jūnis: Ueber die Berechnung des Azimuts aus der Höhe und der Höhe aus dem Azimut." (*Annalen der Hydrographie und maritimen Meteorologie.*)

1920. "Abhandlung des Ḥasan ibn al-Ḥusain ibn al-Haiṭam: Ueber eine Methode, die Polhöhe mit grösster Genauigkeit zu bestimmen." (*De Zee.*)

1921. "Ueber eine arabische Methode die geographische Breite aus der Höhe im 1. Vertical (Höhe ohne Azimut) zu bestimmen." (*Annalen der Hydrographie*, etc.)

1922. "Abhandlungen des al-Ḥasan ibn al-Ḥasan ibn al-Haiṭam (Alhazen) über die Bestimmung der Richtung der Qibla." (*Zeitschrift der deutschen morgenländ. Gesellschaft.*)

1922. "Abhandlung von al-Faḍl ibn Ḥâtim an-Nairîzî: Ueber die Richtung der Qibla." (*Sitzungsberichte des bayer. Akad. der Wissenschaften.*)

1922. "Die Bestimmung der geographischen Breite eines Ortes durch Beobachtung der Meridianhöhe der Sonne oder mittels der Kenntnis 2er anderer Sonnenhöhen und den zugehörigen Azimuten, nach dem arabischen Text der Ḥākimitischen Tafeln des Ibn Yūnus." (*Annalen der Hydrographie*, etc.)

1922. "Abhandlung über die Ziehung der Mittagslinie dem Buche über das Analemma entnommen, samt dem Beweis dazu, von Abū Sa'îd aḍ-Darîr." (*Ibid.*)

1922. "Aus der astronomischen Geographie der Araber." Originalstudien nach al-Qânûn al-Mas'ûdî des Al-Bîrûnî. (*Isis.*)

1923. "Gnomonik der Araber." Berlin.
1923. "Beiträge zur arabischen Trigonometrie." (*Isis.*)
1923. "Ueber den Gnomonschatten und die Schattentafeln der arabischen Astronomie." Hannover.
1924. "Sonnenuhren der spätarabischen Astronomie." (*Isis.*)
1924. "The geography of the Moslems of the Middle Ages." (*Geographical Review.*)
1925. "Die Bestimmung der geographischen Breite der Stadt Ġazna mittels Beobachtungen im Meridian, durch den arabischen Astronomen und Geographen al-Bîrûnî." (*Annalen der Hydrographie,* etc.)
1925. "Drei planimetrische Aufgaben des arabischen Mathematikers Abû'l-Jûd Muḥammed ibn al-Lîth." (*Isis.*)
1925. "Abhandlung des Schaichs Ibn 'Alî al-Hasan ibn al-Hasan ibn al-Haitham: Ueber die Natur der Spuren (Flecken), die man auf der Oberfläche des Mondes sieht." Hannover.
1925. Die trigonometrischen Lehren des Muhammed ibn Aḥmad, Abû'l-Rîhân al-Bîrûnî.

Any such an array of monographs, each based upon a study of original manuscripts, would be impressive merely on the score of number, but in this case the product is even more so in respect to scholarship. To give, as in his article on the "Geography of the Moslems of the Middle Ages," the first translation of the method of Ibn Yûnis for finding longitude by observing solar eclipses; to show by means of a translation from Sibṭ al-Mâridînî that the Egyptians of the Middle Ages were the first to use a sundial directed towards the world pole; to be the first to give us a translation of Ibn 'Alî al-Ḥasan's work on the interpretation of the irregularities of the lunar surface; and to make more clearly known, by accurate translations, the nature of the umbra recta and umbra versa in the leading Arabic works on trigonometry,—these (to mention only a few instances) are gratifying promises of future contributions of great moment. We have by no means solved the problem of the value to be assigned to the Arab contributions to mathematics. Even such a seemingly simple question as that relating to the introduction of our numeral system (or its forerunner) into Bagdad, and somewhat later into Spain, is quite unanswered. We still have the origin of the ġobar numerals to settle, and the story of the other numeral forms in use in the Mediterranean area in the Middle Ages has yet to be written. The sources and the "prodromic symptoms" of the Arabic algebra have still to be searched with greater care; and it seems fair to assert that there is a larger field to be explored than has generally been imagined. The glosses on Euclid alone, as shown in a considerable number of unpublished manuscripts, might well repay the study of the pupils whom Dr. Schoy will gather about him in his new field of labor. He will lecture on the history of Arabic astronomy and trigonometry and will, no doubt, inspire a small group of students to enter the promising field of the study of Arabic manuscripts.

It is, of course, to be hoped that a scholar with such an equipment will soon be enabled to devote all his time to research in the best sense of this much-debased term, and to work with a limited number of sufficiently equipped

students. It would be a great contribution to scholarship in America if a chair could be offered to such a man in one of our own universities.

It may not be out of place to express appreciation of the typographical appearance of at least one of Dr. Schoy's latest works, the *Abhandlung des Schaichs Ibn 'Alî al-Ḥasan ibn al-Ḥasan ibn al-Ḥaitham*, issued by the Orient-Buchhandlung Heinz Lafaire, at Hannover, in 1925. As a piece of printing of a scientific work it leaves little to be desired, and some of our American publishers might do well to examine it as a model of a monograph of its kind.[1]

NOTE ON INVOLUTIONS OF THE *N*TH ORDER

By E. F. ALLEN, University of Missouri

1. Introduction. In the first chapter of Newson's posthumous book on collineations,[2] the theory of linear fractional transformations is developed. The general form of this transformation is

$$x_1=\frac{ax+b}{cx+d}, \tag{1}$$

which is called the explicit form of the transformation. The following well-known properties of this transformation are derived:[3]

(*a*) If $a=d$ and $b=c=0$, then $x_1\equiv x$.

(b) If $a+d=0$, then (1) transforms x into x_1 and also x_1 into x. In this case the transformation is called an involution of the second order.

(*c*) The invariant points of the transformation are[4]

$$(A,A')=\frac{(a-d)\pm\sqrt{(a+d)^2-4(ad-bc)}}{2c}. \tag{2}$$

If the invariant points are distinct the transformation is said to be of type I, otherwise it belongs to type II.

(*d*) Transformations of type I may be written in the form[5]

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[1] The day after reading the proof of the above article word was received of the sudden death of Dr. Schoy, on December 6, 1925, as the result of an apoplectic stroke. He was forty-eight years of age and had not been in good health for some time, as his latest letter to me showed. His funeral took place at Frankfort am Main on December 9. Thus passes away a brilliant scholar and an indefatigable worker. Not until he was about forty years of age did he find his real life work, but in the few years that followed he made remarkable progress. D. E. S.

[2] H. B. Newson, *Theory of Collineations*. Press of the State Printer, Topeka, Kansas.

[3] *Ibid.*, p. 3.

[4] *Ibid.*, p 9.

[5] Newson, p. 10.

$$\frac{x_1-A}{x_1-A'}\cdot\frac{x-A'}{x-A}=k\,, \tag{3}$$

where A and A' are the invariant points of the transformation and k, which is called the characteristic invariant, has the value

$$k=\frac{[(a+d)-\sqrt{(a+d)^2-4(ad-bc)}\,]^2}{4(ad-bc)}\,. \tag{4}$$

It is proved[1] that (3) is an involution of the second order if $k=-1$. Form (3) is called the implicit normal form of type I.

In this note we propose to find a value of k for which (3) is the implicit normal form of an involution of the nth order, and to show that the invariant points of all involutions of form (1), having real coefficients, are conjugate imaginaries, except for the second order involution which may have either real or imaginary invariant points. We shall also derive the explicit form of the involution of the nth order. The discussion shall be limited to transformations of type I, having real coefficients and a non-vanishing modulus.[2]

2. Theorems. We shall prove the following theorems:

THEOREM I. *The necessary and sufficient condition that the invariant points of a linear fractional transformation be conjugate imaginaries is that the characteristic invariant be a complex number, unless $k=-1$, when they may be real.*

THEOREM II. *The implicit form of a linear fractional transformation is an involution of the nth order if k is a primitive root of the equation $k^n-1=0$.*

THEOREM III. *The explicit form of an involution of the nth order is*

$$x_1=\frac{\left(\alpha\sin\frac{\pi l}{n}-\beta\cos\frac{\pi l}{n}\right)x-(\alpha^2+\beta^2)\sin\frac{\pi l}{n}}{\left(\sin\frac{\pi l}{n}\right)x-\left(\alpha\sin\frac{\pi l}{n}+\beta\cos\frac{\pi l}{n}\right)}\,,$$

where α, β $(\beta\neq 0)$ are real numbers and the integer l is prime to n.

3. Proofs of the theorems. Theorem I[3] follows immediately from equations (2) and (4) which show that if k is a complex number the invariant points of the transformation must be conjugate imaginaries, and conversely, unless indeed $a+d=0$, when $k=-1$ in which case we have the well-known second order involution. Equation (2) shows that the invariant points of the second order involution may be either real or imaginary according to the value of the modulus $ad-bc$.

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[1] Newson, p. 22.

[2] The expression $ad-bc$ is called the modulus of the transformation.

[3] See Newson, p. 32, for part of this theorem.

To prove the second theorem we note that the implicit normal form (3) transforms the point x into the point x_1. Likewise

$$\frac{x_2-A}{x_2-A'}\cdot\frac{x_1-A'}{x_1-A}=k \tag{5}$$

transforms the point x_1 into the point x_2. By eliminating x_1 from equations (3) and (5) we obtain

$$\frac{x_2-A}{x_2-A'}\cdot\frac{x-A'}{x-A}=k^2\,, \tag{6}$$

which transforms x directly into x_2.

The necessary and sufficient condition that $x_2=x$ is that $k^2=1$. For if $k^2=1$, equation (6) reduces to $x_2=x$, since we have assumed that the invariant points A and A' are distinct. If $x_2=x$, equation (6) reduces to $k^2=1$. By an easy generalization it is seen that $x_n=x$ if $k^n=1$ and conversely. This proves the theorem.

In order to derive the equation of theorem III let us solve equation (3) for x_1. Thus

$$x_1=\frac{(kA'-A)\,x+AA'(1-k)}{(k-1)x+(A'-kA)}\,. \tag{7}$$

If this is the equation of an involution of the nth order, having imaginary invariant points, then, by theorems I and II, $k=\cos 2\pi l/n+i\sin 2\pi l/n$, $A=\alpha+\beta i$, and $A'=\alpha-\beta i$. When these values of k, A, and A' are substituted in equation (7) we obtain an equation which reduces to the equation of theorem III.

4. Geometric derivation of the formula. The equation of theorem III may be obtained geometrically as follows: Let $P(\alpha,\beta)$ be a point in the xy-plane not on the x-axis. Join $Q(x, 0)$ to P by a straight line and draw another line from P, making an angle of $-l\pi/n$ radians with the line PQ. Call the coordinates of the point R, where this second line intersects the x-axis, $(x_1, 0)$. Then the required equation may be obtained by applying the formula for the angle between two lines.

5. Conclusions. The following conclusions may be drawn from the above discussion: The invariant points of all involutions of type I, having real coefficients, are conjugate imaginaries if the order of the involution is greater than the second. All involutions of order n having imaginary invariant points, can be generated by revolving n equally spaced rays about the point (α, β) $\beta\neq 0$ in the xy plane. The points of the involution are determined by the intersections of these rays with the x-axis. It is possible to construct an in-

volution of the nth order by ruler and compasses if the angle π/n can be constructed by the aid of those instruments. The product of two involutions of orders n and m respectively is an involution of order nm.

QUESTIONS AND DISCUSSIONS

EDITED BY TOMLINSON FORT, Hunter College, Park Ave. and 68th St., New York City.

The department of Questions and Discussions in the Monthly is open to all forms of activity in collegiate mathematics, including the teaching of mathematics, except for specific problems, especially new problems, which are reserved for the separate department of Problems and Solutions.

DISCUSSIONS

I. MINIMIZING THE ARITHMETIC IN SOLUTIONS BY SUCCESSIVE APPROXIMATIONS

By C. C. CAMP, University of Illinois

There are two extremely important considerations in solving equations by the method of successive approximations. One is the rapidity of the convergence to the root and the other is the amount of arithmetical labor required for each new approximation.

Algebra may be regarded as the art of avoiding tedious numerical calculations. On the practical side higher mathematics in general should be an extension of this idea of algebra. In this connection it is surprising how the arithmetic of certain problems in the mathematics of finance can be shortened.

As Professor Forsyth says in his article in the MONTHLY for March, 1925, the convergence of a sequence may be exasperatingly slow. It is believed that three examples will best illustrate a method by which the computing as well as the number of approximations may be diminished.

Taking the problem given, *i. e.*, to find the rate of interest of an annuity of \$1,000 per year for 20 years, whose present value is \$12,102, we have $a_{20} = 12.102$. From Glover's *Tables* the value for five per cent is 12.462 and for five and one-half per cent 11.950. By ordinary interpolation we obtain $.05 + 360/1024$ or .0535 as the first approximation. The iterative method should start here. The use of Schrön's[1] table of logarithms of numbers from 1 to 108,000 is advised for this purpose since the error in any logarithm given in the latter part of the table can be reduced to $\frac{1}{4}$ in the eighth decimal. The 20th power of 1.0535 would have then a maximum error of 7 in the 8th digit, if extreme accuracy is desired. For the first interpolation a slide rule is more

[1] This table of logarithms of numbers can now be had bound and is the handiest 7 (&8) place table available, none being more accurate.

convenient than a calculating machine or a multiplication table such as Crelle's or Peters'.

For a second illustration take the one presented in the MONTHLY (1925), pp. 272-287, by Professor L. R. Ford in his excellent article: Find the return on a five per cent bond due in twenty years bought at 90.

His form (*c*), p. 276, may be written

$$i = r - (A-1)a_n^{-1} = .05 + .1a_{20}^{-1} .$$

If we use $i_1 = .055$, then without interpolation from Glover's *Table*, p. 272, we have $i_2 = .0584$. A simple interpolation gives $i_3 = .05861$ wherein .0070 is the tabular difference for one per cent. Another simple interpolation gives $i_4 = .058621$. One here begins the regular method of successive approximations as given in form (*c*) and by the use of Schrön's table finds $i_5 = .05862111$. This value is in error less than unity in the eighth decimal.

What is emphatic here is the importance of reaching a close approximation as soon as possible. The same is true in using Newton's method. In problems of finding the investment rate, particularly in connection with building and loan associations, the equation can usually be simplified so that the tables may be used for the first few approximations. The numerical work is thus abridged tremendously over that required by methods presented in the best current text books on the mathematics of finance.

Take for example the problem of finding the investment rate from the viewpoint of the borrower in an association which matures its stock on the 79th payment by accepting the regular \$7 interest on a loan of \$1200 but only \$2.40 instead of the regular \$12 dues. To simplify the solution consider first the monthly rate. Then

$$19 + 19a_{78} - 9.60v^{78} = 1200 .$$

Choosing as an initial value $b_1 = 7/12$ per cent, we first approximate to the third term and solve for a_{78}, obtaining

$$a_{78} = 1187.09876/19 = 62.47888 .$$

One interpolation between 7/12 and 5/8 per cent gives $b_2 = .0058526$, all of the digits of which are correct. Hence $i = 7.254$ per cent.

Formula (*B'*), p. 126, in Professor Forsyth's article gives a very slowly converging sequence as may be seen by taking differentials of

$$b_2 = \frac{1-(1+b_1)^{-78}}{62.4784} , \text{ since } db_2 = .786\, db_1 \text{ (nearly).}$$

This method of using differentials for the approximate errors in testing the rapidity of the convergence of a sequence of approximations is quite general

and of wide application not only in the mathematics of finance but also in engineering problems and other fields including the solution of higher algebraic equations.

The method of attack in the case of a sequence which converges slowly will depend on the type of equation to be solved. The use of tables illustrated above is especially appropriate for problems in finance. The author is reserving for a future paper another method of speeding up the convergence in general.

II. Six Decimal Places from a Five-place Table

By L. S. Dederick, University of British Columbia

1. It has probably occurred to most users of mathematical tables that at certain points in certain tables a more accurate value than that given by a single entry may easily be inferred from the neighboring entries, *e. g.*, log cos 16′ or log cos 17′ in a five-place table.

In any part of a table where the second differences are relatively small considerable increase of accuracy can commonly be obtained by merely applying linear interpolation to several pairs of neighboring entries. The reader can easily verify that, aside from the effect of higher differences, the result of linear interpolation is subject to an error not greater than a half unit in the last place if the errors in the entries used are thus restricted. The original entry and the several interpolations therefore each give unit intervals within which the true value must lie. Hence the latter must lie in the part common to all these, an interval commonly much less than a unit.

For example, from a five-place table of common logarithms, $.653205 < \log 4.5 < .653215$. By interpolating between the values for 4.499 and 4.501 we get .653215, which shows that $.653210 < \log 4.5 < .653220$. Also from interpolation between log 4.499 and 4.502, we get $.6532117 < \log 4.5 < .6532217$. Combining these, we get that log 4.5 lies between .6532117 and .6532150, an interval just one-third the size of the original. One can readily verify that the effect of second differences is here negligible. We have thus materially increased the accuracy of the single entry by a trifling amount of labor.

If the process is to be carried further, a selection must be made of values to be used. This can be done by inspecting the tabular differences, seeking on the one hand pairs of entries whose tabular errors appear to be large and positive, and on the other those where they seem large and negative. In the particular example no further improvement in the lower limit presents itself. For the upper limit, if we use the entry for 4.505 combined in succession with those for 4.497, 4.494, 4.491, 4.488, and 4.485, we get successively decreasing upper limits, the last giving us .6532125. So if we could neglect second differences we could assert that $.6532117 < \log 4.5 < .6532125$, or that log 4.5 is

.653212 correct to six places. This is not far wrong but the effect of the second difference has become appreciable for this interval.

2. A much more general method, taking account of differences of all orders that may affect the result, is the following. Let the value of the function near the point investigated be given by the power series $f(x_0+h)=a_0+a_1h+a_2h^2+\cdots$. Then we may form the following differences:

$$\Delta_1(h)=f(x_0+h)-f(x_0-h)=2a_1h+2a_3h^3+2a_5h^5+\cdots,$$

$$\Delta_2(h)=f(x_0+h)-2f(x_0)+f(x_0-h)=2a_2h^2+2a_4h^4+2a_6h^6+\cdots,$$

$$\Delta_3(h)=\Delta_1(2h)-2\Delta_1(h)=12a_3h^3+60a_5h^5+\cdots,$$

$$\Delta_1'(h)=8\Delta_1(h)-\Delta_1(2h)=12a_1h-48a_5h^5+\cdots,$$

$$\Delta_4(h)=\Delta_2(2h)-4\Delta_2(h)=24a_4h^4+120a_6h^6+\cdots,$$

and as many more of the same sort as are needed. If they are formed from the tabulated values each is subject to accumulated tabular errors. These may amount to a maximum of 1 in Δ_1, 2 in Δ_2, 3 in Δ_3, 9 in Δ_1', 8 in Δ_4, etc., reckoned in units of the last decimal place. These maxima are independent of the value of h. From these we may write

$$a_1=\frac{\Delta_1\pm 1}{2h}-a_3h^2+\cdots=\frac{\Delta_1'\pm 9}{12h}+4a_5h^4+\cdots,$$

$$a_2=\frac{\Delta_2\pm 2}{2h^2}-a_4h^2+\cdots,\quad a_3=\frac{\Delta_3\pm 3}{12h^3}-5a_5h^2+\cdots,$$

expressions in which the error may be made very small by taking a large value of h. In all ordinary cases the values of the successive coefficients decrease rapidly, so that it is not necessary to find many of them. The accuracy of any one may be increased by using two values of h and thus confining the value of the required coefficient to the smaller interval common to two intervals that overlap. By using alternative forms, such as the second given for a_1, it is possible to eliminate from the formula for one coefficient all later coefficients that would have any appreciable effect, for the value of h used.

We put these relatively accurate values of a_1, a_2, $\cdots$ in the power series, and write $a_0=f(x_0+h)-s(h)$, where $s(h)=a_1h+a_2h^2+\cdots$. The error in the tabular value of $f(x_0+h)$ is not more than $\frac{1}{2}$. The error in $s(h)$ may be kept very small if the values of h are taken much smaller than those used in determining the coefficients. By using a number of values for h we get a number of overlapping intervals within which a_0, the true value of the function, must lie. The part common to these will in general be much smaller than any one, and we may thereby increase the accuracy to a considerable extent, frequently enough to get another decimal place, sometimes more than this.

As an illustration, let us seek from a five-place table a more accurate value for log 1.7 than .23045, the one given. Using Δ_1' with $h=103$ and 102 we get $25.545<a_1<25.548$ (using for units the least count of the table). Likewise we may get $.00746<-a_2<.00758$ and $.00000290<a_3<.00000305$. The value of a_4 is too small to determine even its sign from values of h in the neighborhood of 100. With mean values of these coefficients we form $f(x_0+h)-s(h)$ for various values of h. This gives 23044.43 for $h=3$, and 23045.38 for $h=-13$. These would give $23044.88<a_0<23044.93$ if the coefficients were strictly correct. To be sure of the limits, however, we should use the most unfavorable values of the coefficients in each case. These give $.2304485<\log 1.7<.2304494$, or $\log 1.7=230449$ correct to six decimals.

The probable number of values of h necessary to consider in order to increase the accuracy tenfold is discussed in Problem No. **3160** in this issue of the MONTHLY.

Limitations of space forbid the presentation of methods for systematizing, refining, and abbreviating the necessary computations.

3. A somewhat more accurate result may often be obtained by applying to the earlier interpolation method corrective terms based on the coefficients of the power series. Thus

$$a_0=\frac{hV+Hy}{h+H}-a_2hH-a_3hH(H-h)\cdots,$$

where $V=f(x_0+H)$ and $y=f(x_0-h)$. In the last example if we use $h=13$, $H=23$ for a lower limit, and $h=25, H=3$ for an upper limit, we get $.2304486<\log 1.7<.2304493$, a result slightly better than the preceding.

Of these two methods the first is always, and the second frequently, within the realm of practical computation, that is will involve less work than computing the value of the function *de novo*.

4. Another method, having a wider application, is that of trial and error. This is more laborious, but can be applied to a short table, where the large values of h used in the preceding method for finding the coefficients, are not available. This method consists of subtracting from the tabulated values the values of a polynomial so chosen (by inspection) as to give small residues near the point investigated. This process is repeated until a certain range of residues is obtained lying between $-\frac{1}{2}$ and $\frac{1}{2}$. The subtraction is then continued of polynomials so chosen as to extend the range of such residues in each direction. The residues for the special value investigated will then approximate to the tabular error.

III. Note on the Convergence of Fourier Series[1]

By Dunham Jackson, University of Minnesota

In a recent number of the Monthly, Franklin has given a particularly clear and simple proof of the convergence of Fourier series under hypotheses general enough to cover the most important applications.[2] The conditions on the function to be represented may be essentially paraphrased by saying that it has the period 2π, and that a period interval can be divided into a finite number of subintervals, in each of which, considered by itself, the function has a continuous derivative, if suitably defined at the ends of the subinterval, though there may be a discontinuity in passing from one subinterval to the next.

The purpose of this note is to arrive at the same result by a proof which is believed to be still simpler in the character of its reasoning, though perhaps not very much shorter when spread on paper.

It is convenient to keep the notation and the identical language of Franklin's paper to a point a little above the middle of page 477, through the lines

"Thus the equation in question will follow from . . . .

$$\lim_{n=\infty} \int_0^\pi [f(u+x)-f(x+)]s_n du=0 .$$"

Then the proof proceeds as follows:

Let $\varphi(x)$ be an arbitrary function which is bounded and integrable from $-\pi$ to π (but not necessarily periodic nor defined in any way outside this interval), let α_n, β_n be its Fourier coefficients:

$$\alpha_n=\frac{1}{\pi}\int_{-\pi}^{\pi}\varphi(t)\cos nt\,dt , \qquad \beta_n=\frac{1}{\pi}\int_{-\pi}^{\pi}\varphi(t)\sin nt\,dt ,$$

and let

$$\sigma_n=\tfrac{1}{2}a_0+\sum_{m=1}^{n}(a_m\cos mx+\beta_m\sin mx) .$$

Then

$$\frac{1}{\pi}\int_{-\pi}^{\pi}[\varphi(x)-\sigma_n(x)]^2dx=\frac{1}{\pi}\int_{-\pi}^{\pi}[\varphi(x)]^2dx-\left[\tfrac{1}{2}a_0^2+\sum_{m=1}^{n}(a_m^2+\beta_m^2)\right] .$$

As the left-hand member can not be negative, the sum on the right must remain bounded as n increases indefinitely, the series

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[1] Presented to the American Mathematical Society, October 31, 1925.

[2] P. Franklin, A simple discussion of the representation of functions by Fourier series, this Monthly, (1924) pp. 475-478.

$$\sum_{m=1}^{\infty} (a_m^2+\beta_m^2)$$

must converge, and it must be that[1] $\lim_{n=\infty} a_n=0$, $\lim_{n=\infty} \beta_n=0$. Since $\varphi(x)\cos\frac{1}{2}x$ and $\varphi(x)\sin\frac{1}{2}x$ satisfy the conditions imposed on $\varphi(x)$, the integrals

$$\int_{-\pi}^{\pi} \varphi(t)\sin\tfrac{1}{2}t\cos nt\,dt\,, \qquad \int_{-\pi}^{\pi} \varphi(t)\cos\tfrac{1}{2}t\sin nt\,dt$$

approach zero as n becomes infinite, and their sum

$$\int_{-\pi}^{\pi} \varphi(t)\sin(n+\tfrac{1}{2})t\,dt$$

does the same.

If $\psi(x)$ is bounded and integrable from 0 to π, the function $\varphi(x)$ which is equal to $\psi(x)$ for $0<x\leqq\pi$, equal to $-\psi(-x)$ for $-\pi\leqq x<0$, and equal to 0, say, for $x=0$, is bounded and integrable from $-\pi$ to π, and the integral

$$\int_{-\pi}^{\pi} \varphi(t)\sin(n+\tfrac{1}{2})t\,dt = 2\int_0^{\pi} \psi(t)\sin(n+\tfrac{1}{2})t\,dt$$

still has the limit zero.

But, under the hypotheses of the theorem, the function

$$\psi(u)=\frac{f(x+u)-f(x+)}{2\sin u/2}=\frac{f(x+u)-f(x+)}{u}\cdot\frac{u/2}{\sin u/2}$$

is bounded and integrable for $0<u\leqq\pi$, since it has essentially the same discontinuities as $f(x+u)$ in the open interval, and approaches a limit as u approaches zero from the right. Consequently[2]

$$\lim_{n=\infty}\int_0^{\pi}[f(u+x)-f(x+)]s_n du=\lim_{n=\infty}\int_0^{\pi}\psi(u)\sin(u+\tfrac{1}{2})u\,du=0\,.$$

It may be pointed out that this proof does not require that the derivative of $f(x)$ be continuous.

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[1] *Cf., e. g.*, M. Bôcher, Introduction to the theory of Fourier's series, *Annals of Mathematics*, vol. 7 (1906), pp. 81-152; p. 86.

[2] Cf. de la Vallée Poussin, *Leçons sur l'approximation des fonctions d'une variable réelle*, Paris, 1919; pp. 19-20.

RECENT PUBLICATIONS

EDITED BY W. B. CARVER, Cornell University, to whom books and communications should be sent.

REVIEWS

(a) *Ve-Po-Ad.* Chicago, Reliable Typewriter and Adding Machine Corp. Price $2.95.

(b) *Baby Calculator.* Chicago, Baby Calculator Sales Co. Price $2.50.

These two pocket adding machines are constructed on exactly the same principle. For each column of figures there is a slider, which is free to move vertically. This bears the digits 0 to 9, some one of which is visible at any time through a window in the fixed face of the machine, and indicates the result arrived at in that column. The slider has teeth projecting on both sides, placed at the same interval from each other as the digits . Those projecting on the left are accessible through a vertical slot in the face, situated below the window for that column and slightly to the left of it. Adjacent to this slot the face bears the digits 1 to 9 at the same intervals as those on the slides.

The machine is operated by placing the point of a stylus between two teeth and pushing the slides up or down. To add a given digit the point is placed in the interval opposite where this digit appears on the face, and is then pushed to the bottom or to the top of the slot, the choice being indicated to the eye by a difference in coloration of the teeth. The latter case is that where "carrying" is necessary. This is accomplished by what is the most characteristic device of the machines. Each slot is widened toward the left at the top for a distance corresponding to one unit. The operation requires that whenever the stylus is brought to the top of the slot it is carried on around to the left and down, thereby engaging the right hand teeth of the next slides to the left, moving it one unit, and thus "carrying one." A little more manipulation is necessary in case the column to the left happens to register 9.

The Baby Calculator allows for the addition of seven figure numbers to a seven figure total; the Ve-Po-Ad, of eight figure numbers to a nine figure total. The extreme column on the left in the Ve-Po-Ad is used only for carrying. Both instruments are unnecessarily hard on the eyes. In the Ve-Po-Ad, this trouble is due to the figures on the sliders. These are red on a shiny metallic background, and are almost invisible in most lights that do not give a glare from the metallic surface. There is the same sort of objection to the figures on the face of the Baby Calculator, which are shiny brass on shiny black. The sliders of the Baby Calculator and the face of the Ve-Po-Ad are optically satisfactory. The Ve-Po-Ad presents a more pleasing appearance, and is easier to operate, the Baby Calculator having a decidedly stiff action. This becomes slightly easier with use but not much. The Ve-Po-Ad has a permanent cover

of some leather-like material, which opens like a note-book. This adapts it better to carrying in the pocket. It is not as suitable to the vest pocket, however, as the Baby Calculator, being too wide. In fact the names would be more suitable if interchanged.

The operation of subtraction is provided for by a second set of figures for each column, which appears on the face of the machine.They are distinguished from the addition figures by being made much smaller. In subtracting, these figures are used in the same way as the larger ones for addition, except for the procedure when the stylus reaches the top or bottom of the slot. At the top it is not to go around to the left and down as in addition. When it reaches the bottom, "borrowing" is necessary, and this must be performed separately, the stylus being taken out and removed to the widened part at the top of the slot. It seems unfortunate that a similar widening at the bottom is not provided for this purpose, and its absence probably increases the time taken in subtraction nearly fifty per cent.

The instruction pamphlet for the Ve-Po-Ad deals with addition only. That for the Baby Calculator gives full directions for subtraction. Its treatment of multiplication and division, however, is very brief and inadequate. The user must develop the technique of these operations for himself. The directions for division are particularly poor, the method given being solely repeated subtraction. This, while satisfactory for the larger and more mechanically operated machines, would be extremely tedious with these small ones. The ordinary process, such as is used on paper, is much shorter. In both multiplication and division of large numbers, the work may be arranged so that the figures of the dividend or the multiplicand are gradually removed to make room for those of the product or quotient. In multiplication this may be done either from left to right or from right to left. For repeated multiplications it is well to use both methods, as corresponding significant figures are moved to the left in the one case, to the right in the other.

The extent to which one of these machines is a time saver depends on a variety of circumstances. It seems certain, however, that it is a great labor saver. Even if no saving of time at all is effected, the concentration necessary to perform the operations mechanically is much less than that required to perform them mentally. For many purposes the use of two of these machines in conjunction is very convenient. Sometimes the second may be used for subsidiary computations. More often the advantage consists in carrying intermediate results on one machine when positive, on the other when negative, in the case of substituting in a polynomial or similar formula.

L. S. DEDERICK.

History and Synopsis of the Theory of Summable Infinite Processes. By L. Smail. Eugene, Ore., University of Oregon Press, 1925. vi+175 pages. Price $2.00

This book contains first a three-page section entitled "Early History." In this the author goes back to views of Leibniz and Euler on $1-1+1-1+\cdots$ and to those of Cauchy and Abel on convergence, from them bringing the history of summable series down to Borel. Little of interest is presented. The facts stated are n the main well known to every mathematician interested in infinite series and no one else would be in the least interested in the book. However, the pages consumed are few. In the opinion of the reviewer it is a pity that an orderly historical account of later developments is not given.

The second and main part of the book entitled "Synopsis" consists of one hundred and seventy pages of abstracts of papers and books by one hundred and fifteen authors, arranged according to year of publication. Something like two hundred and seventy-five titles are cited running from 1880 to 1923. As a bibliography it is more complete than anything already in the field. Ford in his "Studies on Divergent Series and Summability" published in 1916 cites ninety-seven authors and about two hundred papers. He includes papers on asymptotic series.

Many of the abstracts were compared by the reviewer with the corresponding abstracts in the *Jahrbuch über die Fortschritte der Mathematik*. In the case of a few American dissertations no corresponding abstract exists in the *Jahrbuch*; and in many instances, particularly where articles in English are concerned, Smail gives the more lengthy and better abstracts. In a few instances the reverse is true. However, as it will probably be several years before the *Jahrbuch* is carried through 1923, Smail presents a more complete piece of work than would be afforded at the present time by a simple bibliography in conjunction with the *Jahrbuch*.

On the whole we have a very carefully prepared volume and one that will prove useful to every one interested in summable processes.

TOMLINSON FORT.

ARTICLES IN CURRENT PERIODICALS

The lists appearing regularly in the Monthly of articles in current periodicals are intended to include (1) titles of papers in all mathematical journals published in the United States; (2) titles of mathematical papers and reports published by the national and state academies of science and in journals devoted to general science; (3) titles of mathematical papers by American authors published in foreign journals.

American Journal of Mathematics, volume 47, no. 3, July, 1925: "A configuration of Thirteen Pencils of Cubics and Cubics with Three Real Inflexions" by M. B. Turner, 149-162; "A Mathematical Theory of Competition" by C. F. Roos, 163-175; "Imprimitive Substitution Groups" by G. A. Miller, 176-180; "Classifications of Monoidal Involutions having a Fixed Tangent Cone" by Marian M. Torrey, 181-206; "Self-Projective Rational Septimics" by R. M. Winger, 207-223.

Annals of Mathematics, second series, volume 26, no. 4, June, 1925: "On continued fractions in the theory of binary forms" by A. Arwin, 247-272; "A property of sequences of Laplace" by H. L. Olson, 273-277; "Green's Lemma" by H. E. Bray, 278-286; "A class of minimum problems and the linear independence of functions of one variable" by O. Dunkel, 287-308; "Tables of quadratic forms" by A. E. Cooper, 309-316.

Bulletin of the American Mathematical Society, volume 31, no. 8, October, 1925: "Concerning the Complementary Intervals of Countable Closed Sets" by J. R. Kline, 409-410; "On Sets of Three Consecutive Integers which are Quadratic Residues of Primes" by A. A. Bennett, 411-412; "Groups in which the Normalizer of every Element except Identity is Abelian" by Louis Weisner, 413-416; "Note on Gibbs' Phenomenon" by C. N. Moore, 417-419; "A Historical Note on Gibbs' Phenomenon in Fourier's Series and Integrals" by H. S. Carslaw, 420-424; "A General Form of the Suspension Bridge Catenary" by Ira Freeman, 425-429; "On the Solution of Diophantine Equations by means of Ideals" by G. E. Wahlin, 430-444.

Science, new series, volume 62, no. 1606, October, 1925; "Arithmetization in the History of Mathematics" by G. A. Miller, 328.

The Tohoku Mathematical Journal, volume 25, nos. 1, 2, May, 1925: "On a series of functions formally analogous to Fourier's Series" by W. P. Udinsky, 1-23; "Determination of plane algebraic curves which are invariant under involutory Cremona transformations" by A. Emch, 63-76.

UNDERGRADUATE MATHEMATICS CLUBS

All reports of club activities should be sent to H. J. Ettlinger, 2910 Harris Park Ave., Austin, Texas

CLUB ACTIVITIES

DENSION MATHEMATICS CLUB, Dension University, Granville, O.

[*1924*, 453]

The following are the subjects and speakers of the Denison Mathematics Club for the year 1924 1925:

January 15, 1924. "The perpetual calendar" by Lester Hunt. "What is wrong with the present-day calendar?" by Leland Powell. "The advantages of the proposed calendar" by Samuel Treharne.

A prize problem is given out at certain meetings and students are to bring in solutions at the next meeting. A decision as to who has the best solution is made. At this meeting Dr. Wiley explained the prize problem.

February 5. Short play on "The third dimension" was given. Social meeting. Interesting problems and puzzles were worked.

February 19. "Do negative numbers have logarithms?" by Leslie Bone, Hazel Dunlap and Kendrick Holt.

March 18. "Rubbing elbows with infinity" by Dr. Wiley.

May 2. Sixth annual banquet at Hotel Warden, Newark, Ohio.

May 13. "Probability" by Dr. Wiley.

October 7. "Mathematical fallacies" by Mr. Gay and Mr. Bash. Dr. Barnum from Constantinople, who had exchanged places for the year with Dr. Wiley was introduced.

October 21. "Duality" by Dr. Barnum.

November 11. "Kinds, forms and constituents of nebulae" illustrated with lantern slides by Turpin Bomeister.

December 16. Christmas social. Stunts, puzzles and a mathematical spelldown.

February 3, 1925. "New ways with series" by Professor Leman.

March 3. Prize problem stated by Professor Leman. Explanations and solutions are to be brought in later.

March 17. Miss Peckham addressed the club.
April 21. "How straight is a straight line?" by Mr. Bone.
May 5. "Applications of mathematics" by Miss Tippets.
May 19. Explanations of prize problem. Announcement of winners. Plans for club banquet on June 5.

(Report by Miss Josephine Deeds, Secretary)

The Mathematics Club of the University of Oklahoma, Norman, Okla.

[*1923*, 335]

The program of the Mathematics Club of the University of Oklahoma for the year 1924-1925 was the following:

October 23, 1924. "The theory of the number system" by Mr. Allen E. Andersen.
December 11, 1925. "The slide rule" by Professor E. R. Page.
January 15. "Ancient Egyptian and Babylonian mathematics" by Eugene Dunlap. "The regular heptagon" by Orlan Harden.
February 12. "Relation of physics to mathematics" by Professor W. Schriever.
February 26. "Transcendental numbers" by Hannah E. Brauer.
March 12. "Perfect numbers" by Eugene Springer. "Irrational numbers" by Mrs. Meagher.
March 26. "The electron theory" by Mr. D. E. Roller.

(Report by Frances M. Wright)

The Mathematics Club of Wellesley College, Wellesley, Mass.

[*1924*, 497]

The officers elected for the year 1924-1925 were: Doris Alexander '25, president; Loretta Davis '25, vice-president; Mildred Larimer '25, senior executive; faculty executive, Professor Helen Merrill; Eleanor Loomis '26, secretary and treasurer; Dorothy Dodd '26, junior executive.

At the club meeting, the following programs were presented:

October 21, 1924. "My experiences at the International Congress of Mathematicians" by Professor Clara Smith.
December 12. Mathematical puzzles and charades by juniors, seniors and faculty.
February 13, 1925. "Growth and development of number systems" by Isobel Hutchison '25. "Survey of the history of Greek mathematics" by Margaret Harris '25. "Problems of ancient mathematics" by Loretta Davis '25. "A famous woman mathematician" by Mildred Larimer '25.
March 13. "History of mathematics from the Renaissance to Vieta" by Nina Hammond '26. "History of mathematics from Vieta to Newton" by Ruth Mason '26. "History of mathematics from Newton to Euler" by Margaret Lane '26.
April 14. "Old and rare mathematics books" by Professor Lennie P. Copeland.
May 15. "History of the development of analytic methods in modern mathematics" by Professor Clara Smith. "Development of geometrical methods in modern mathematics" by Professor Mabel Young.

The following officers were elected for the year 1925-1926: Elizabeth Maxon '26, president; Nina Hammond '26, vice-president; Charlotte Banta '26, senior executive; Professor Lennie Copeland, faculty executive.

(Report by Miss Maxon)

Newtonian Society, State College of Washington, Pullman, Wash.

[*1924*, 453]

The officers of the Newtonian Society for the year 1924-1925 were: Kathryn Maloney, president; Marion Upton, secretary-treasurer; Frances Helmer, reporter.

The following papers were presented at the meetings in 1924-1925.

January 20, 1925. "Formal logic" by Professor C. A. Isaacs.
February 17. "Determination of π" by Fern Bolich. "Life of Newton" by Marion Upton.

March 3. "Mathematical notation and terminology" by Professor Colpitts.
March 17. "Common fractions" by Ruth Himmelsbach. "Simple continued fractions" by Walter Bond.

Special meetings were held on December 8, 1924 and March 31, 1925.

(Report by Professor Isaacs)

Fi Mu Epsilon, Syracuse University, Syracuse, N. Y.

[*1924*, 494]

The officers for the year 1924-1925 were: Professor F. N. Bryant, director; Miss May J. Sperry, instructor, vice-director; Julia Bower '25, secretary; treasurer, Reginald Steele; Dorothy Park, librarian; Helen O'Donnell '26, Kenneth Robertson '25, Warren Lyon, instructor, Louis Rees, instructor, additional members of the executive committee; Dr. W. G. Bullard, Dr. W. F. Taylor, Vera Keeney '25, Ruth Woodworth '25, Julia Bower '25, scholarship committee.

The programs for the year were:

January 6, 1925. "Applications of complex quantities in engineering" by Mr. Clarke. "The planimeter" by Mr. Bothwell. "The slide rule" by Mr. Johnson.
February 10. "Systems of numeration" by Miss Garrett. "Life of Laplace" by Miss Keeney. "The three great problems of the Greeks" by Miss Woodworth.
March 3. "How to find the contents of a horizontal storage tank" by Mr. Hosier. "Derivation of the kinetic theory of gases" by Mr. McCarthy. "Stadia surveying" by Mr. Kaufmann.
April 3. "Magic figures" by Miss Keeney. "The papyrus of Ahmes" by Miss Fayle. "Early days and former members of the club" by Dr. Decker.
April 28. "Mortality tables" by Mr. Albright. "Statistical study of the relation between grades and cuts" by Miss Gilbert and Miss Shipston.

Some interesting social meetings have been held:

December 12, 1924. Initiation. A successful "get-acquainted" program was given by Liberal Arts.
February 10, 1925. "Mathematical magic" terminated by a flashlight picture of the Fraternity for the 1926 "Onondagan." The meeting adjourned to the drafting room of the College of Applied Science where Pi Mu Epsilon cross word puzzles were worked out.
March 3. A clever mock-meeting was presented by the Engineers.

(Report by Professor E. D. Roe, Jr.)

PROBLEMS AND SOLUTIONS

Edited by B. F. Finkel, Otto Dunkel, and H. L. Olson.

Send all communications about Problems and Solutions to B. F. Finkel, Springfield, Mo. All manuscripts should be typewritten, with double spacing and with a margin at least one inch wide on the left.

PROBLEMS FOR SOLUTION

[N. B. Problems containing results believed to be new, or extensions of old results are especially suoght. The editorial work would be greatly facilitated if, on sending in problems, proposers would also enclose any solutions or information that will assist the editors in checking the statements. In general, problems in well-known textbooks, or results found in readily accessible sources, will not be proposed as problems for solution in the Monthly. In so far as possible, however, the editors will be glad to assist members of the Association with their difficulties in the solution of such problems.]

3156. Proposed by R. E. Gaines, University of Richmond, Va.

A *given* ellipse always touches a fixed straight line at a given point; find the locus of its center. Find the locus of the focus of a parabola under similar conditions.

3157. Proposed by Dr. Bernardo Ig. Baidaff, Buenos Aires, Argentina.

Calculate

$$\begin{matrix}(x & (& x\cdots & (x & (& xe^x)' &)'\cdots &)' &)' \\ p & p-1 & & 2 & 1 & 1 & 2 & p-1 & p\end{matrix} \qquad (1)$$

$$\begin{matrix}(x & (& x^2\cdots & (x^{p-2}(x^{p-1}(x^p)' &)'' &)'''\cdots &)^{(p-1)})^{(p)}\\ p & p-1 & & 3\quad 2\quad 1\;1 & 2 & 3 & p-1 & p\end{matrix}, \qquad (2)$$

where the accents $'$, $''$, $\cdots$ mean the first, second, $\cdots$ derivatives, and where the parentheses are paired as indicated by the numbers under them.

3158. Proposed by Otto Dunkel, Washington University.

Show that the absolute values of the imaginary roots (also of the negative roots when n is even) of the equation

$$x^{n+1}-(k+1)x^n+k=0, \quad k>0, \quad n\geqq 2,$$

lie between $\sqrt[n]{k/(k+2)}$ and unity; also that the absolute values of the imaginary roots are greater than that of the negative root of (a) the given equation when n is even, of (b) the equation obtained by replacing n by $n-1$ when n is odd.

If $k\geqq 1$ the absolute values of the imaginary roots (and negative roots) lie between .61 and 1.

3159. Proposed by R. H. Sciobereti, Berkeley, California.

Determine and discuss the nature of the curve described by the extremity of the shadow of a vertical rod on the horizontal plane.

3160. Proposed by L. S. Dederick, University of British Columbia.

All values of a continuous variable between 0 and 10 are equally likely. What is the most probable number of values that must be selected at random before obtaining two that differ by more than 9?

Is the result the same if the phrase "most probable" is taken literally as if it has the common meaning as applied to errors, as likely as not to be exceeded?

3161. Proposed by C. K. Robbins, Purdue University.

A non-degenerate conic and its tangents are inverted in $x^2+y^2=1$.

Show that the locus of the centers of the circles, which are the inverses of the tangents to the conic, is a conic.

3162. Proposed by J. L. Riley, Ouachita College, Arkadelphia, Ark.

Give an integral solution of $z^2=ay^2+x^2$.

3163. Proposed by Norman Anning, University of Michigan.

"....the fair pearl necklace of the Queen,
That burst in dancing, and the pearls were spilt;
Some lost, some stolen, some as relics kept.
But nevermore the same two sister pearls
Ran down the silken thread to kiss each other
On her white neck—" —From *Vivien* by Tennyson.

Suppose the clasps alone remained upon the string while 50 pearls were spilt and 40 found; what is the chance of stringing these afresh to fit the poet's fancy?

SOLUTIONS

3120 [1925, 137] Proposed by V. M. Spunar, Chicago, Illinois.

If ρ_1 and ρ_2 be the greatest and least radii of curvature of a curved surface at a given point; φ and ψ, the angles which the normal to the surface at the given point makes with the axes of x and y, show that

$$1/\rho_1+1/\rho_2 = \frac{d}{dx}(\cos\psi)+\frac{d}{dx}(\cos\psi)$$

SOLUTION BY R. H. SCIOBERETI, Berkeley, California.

Let l, m, n, be the direction cosines of the normal to the surface at point $M(x, y, z)$, the system of reference being three rectangular axes Ox, Oy, Oz. From the classical theory of curved surfaces it is well known that:

$$l=\cos\phi=\frac{p}{\sqrt{1+p^2+q^2}}, \quad m=\cos\psi=\frac{q}{\sqrt{1+p^2+q^2}}, \quad n=\frac{1}{\sqrt{1+p^2+q^2}}$$

where $$p=\frac{\partial f}{\partial x} \quad \text{and} \quad q=\frac{\partial f}{\partial y}.$$

Furthermore, the principal radii of curvature at the point M are the roots of the following quadratic equation:

$$(rt-s^2)\rho^2-\sqrt{1+p^2+q^2}[(1+p^2)t-2pqs+(1+q^2)r]\rho+(1+p^2+q^2)^2=0,$$

where r, s, and t have their usual meaning, *i.e.*

$$r=\frac{\partial p}{\partial x}, \qquad s=\frac{\partial p}{\partial y}=\frac{\partial q}{\partial x}, \qquad t=\frac{\partial q}{\partial y}.$$

Now from the theory of symmetric functions, the sum of the reciprocals of the roots will be:

$$1/\rho_1+1/\rho_2=\frac{\sqrt{1+p^2+q^2}[(1+p^2)t-2pqs+(1+q^2)r]}{(1+p^2+q^2)^2}$$

which may be written

$$\frac{\left(1+p^2+q^2\right)\frac{\partial q}{\partial y}-q\left(p\frac{\partial p}{\partial y}+q\frac{\partial q}{\partial y}\right)}{(1+p^2+q^2)^{3/2}}+\frac{\left(1+p^2+q^2\right)\frac{\partial p}{\partial x}-p\left(p\frac{\partial p}{\partial x}+q\frac{\partial q}{\partial x}\right)}{(1+p^2+q^2)^{3/2}},$$

or

$$(1+p^2+q^2)^{-1/2}\frac{\partial q}{\partial y}-\frac{\left(p\frac{\partial p}{\partial y}+q\frac{\partial q}{\partial y}\right)}{(1+p^2+q^2)^{3/2}}q+(1+p^2+q^2)^{-1/2}\frac{\partial p}{\partial x}-\frac{\left(p\frac{\partial p}{\partial x}+q\frac{\partial q}{\partial x}\right)}{(1+p^2+q^2)^{3/2}}p$$

or

$$\frac{\partial}{\partial y}\left[\frac{q}{\sqrt{1+p^2+q^2}}\right]+\frac{\partial}{\partial x}\left(\frac{p}{\sqrt{1+p^2+q^2}}\right); \text{ hence}$$

$$\frac{1}{\rho_1}+\frac{1}{\rho_2}=\frac{\partial}{\partial x}(\cos\varphi)+\frac{\partial}{\partial y}(\cos\psi).$$

NOTE. The last equation in the statement of the problem seems to be incorrect, and ought to be,

$$1/\rho_1+1/\rho_2=\frac{\partial}{\partial x}(\cos\varphi)+\frac{\partial}{\partial y}(\cos\psi)$$

Also solved by CONSTANCE R. BALLANTINE.

3121 [1925, 137]. **Proposed by A. A. Bennett, University of Texas.**

Find the smallest positive integer x, not a multiple of 31, such that x^2+1 shall have two factors whose difference is divisible by 31.

SOLUTION BY CONSTANCE R. BALLANTINE, New York University.

The quadratic residues of 31 are:

$$0, 1, 2, 4, 5, 7, 8, 9, 10, 14, 16, 18, 19, 20, 25, 28.$$

From these we select each r such that $r+1$ is also a residue, obtaining

$$x^2 \equiv 1, 4, 7, 8, 9, 18, 19 \pmod{31}.$$

($x^2 \equiv 0$ is ruled out by the conditions of the problem.)

Let $x^2+1=yz$, $y=t+31u$, and $z=t+31v$, where $0<t<31$. Then

$$x^2+1=t^2+31t(u+v)+961uv \equiv 2, 5, 8, 9, 10, 19, 20 \pmod{31};$$

whence $t=3, 6, 8, 9, 12, 14, 15, 16, 17, 19, 22, 23, 25, 28$.

If the prime p divides t, we have

$$961uv-1 \equiv r \pmod{p},$$

where r is a quadratic residue of p. Since 3 divides more of the possibile values of t than any other odd prime, let us examine the congruence

$$961uv-1 \equiv 0, 1 \pmod{3},$$

or

$$uv \equiv 1, 2 \pmod{3}.$$

Since u and v are integers and $u \neq v$, $u=1$, $v=2$ is the smallest set of values possible. This gives us for $t=3$,

$$yz = 34 \cdot 65 = 2210 = 1+47^2.$$

Thus $x=47$ is a solution.

Since 3 is the smallest value of t, a smaller value for x could be obtained only by taking $u=0$ or $v=0$.

This requires that -1 be a quadratic residue of each prime factor of t, which limits the values of t to 8, 16, 17, and 25.

Taking $u=0$, $t=8$, we have

$$64+248v = x^2+1 < 2210,$$

if we are to have $x<47$. Hence $v<9$. Since $x^2=248v+63$, we have

$$2v \equiv 0, 1 \pmod{3}$$

$$v \equiv 0, 2 \pmod{3}.$$

Also,

$$3v \equiv 0, 1, 2, 4 \pmod{7},$$

$$v \equiv 0, 5, 3, 6 \pmod{7},$$

and

$$8v+3 \equiv 0, 1, 4, 9, 6, 5 \pmod{10} \text{ or}$$

$$v \equiv 1, 2, 4 \pmod{10}.$$

Therefore, $t=8$ gives no solution.

Taking $u=0$, $t=16$, we have

$$256+496v < 2210,$$

$$v < 4.$$

To make $496v+255$ a square, we must have

$$v \equiv 0, 1 \pmod{3},$$

$$6v+3 \equiv 0, 1, 2, 4 \pmod{7},$$

$$v \equiv 1, 2, 3, 6 \pmod{7}.$$

Hence $v=1$ or 3.

These values of v give $yz=752$ and $yz=1744$ respectively. Since neither 751 nor 1743 is a square, $t=16$ gives no solution.

Taking $u=0$, $t=17$, we have

$$289+527v < 2210,$$

$$v < 4.$$

To make $527v+288$ a square, we must have

$$2v \equiv 0, 1 \pmod{3},$$

$$v \equiv 0, 2 \pmod{3},$$

$$2v+1 \equiv 0, 1, 2, 4 \pmod{7},$$

$$v \equiv 0, 3, 4, 5 \pmod{7}.$$

The one possible value of v is 3, but this gives $yz=1870$, and 1869 is not a square.

For $u=0$, $t=25$,

$$625+775v<2210,$$
$$v<3.$$
$$775v+624\equiv 0,\ 1 \pmod 3,$$
$$v\equiv 0,\ 1 \pmod 3.$$

But $v=1$ gives $yz=1400$, and 1399 is not a square.

Thus 47 is proved to be the least value of x.

Also solved by F. L. WILMER and E. E. WHITFORD.

3123 [1925, 138]. **Proposed by B. F. Finkel, Drury College.**

A circular hole, radius r, in the bottom of a flat-bottomed water-tank is covered with a weightless spherical rubber shell, radius R. Water is then poured into the tank to the depth h. What is the ratio of R to r when the shell is just on the point of rising?

SOLUTION BY E. M. BERRY, Purdue University

The force F_1 tending to keep the shell from rising equals the weight of a vertical column of water having the area of the hole as base and whose altitude is h. This gives

$$F_1=\omega\pi r^2h \tag{1}$$

where ω is the weight of a unit volume of water.

The force F_2 tending to cause the shell to rise is equal to the weight of water displaced.

Taking the origin at the center of the sphere and the element of volume as a thin disk parallel to the bottom of the tank, we have

$$F_2=\omega V=\pi\omega\int_{z_1}^{z_2}(R^2-z^2)dz \tag{2}$$

where V is the volume of water displaced.

Case 1—The water does not cover the shell, then

$$z_2=h-\sqrt{R^2-r^2},\qquad z_1=-\sqrt{R^2-r^2}$$

and we get from (2)

$$F_2=\omega\pi(r^2h-\tfrac{1}{3}h^3+h^2\sqrt{R^2-r^2}).$$

The shell is just on the point of rising when $F_1=F_2$; hence we have

$$h=3\sqrt{R^2-r^2} \tag{3}$$

Case 2—The water covers the shell entirely, then $z_2=R$ and $z_1=-\sqrt{R^2-r^2}$ and (2) becomes

$$F_2=\tfrac{1}{3}\omega\pi\left[2R^3+(2R^2+r^2)\sqrt{R^2-r^2}\right].$$

Putting $F_1=F_2$ we get

$$3r^2h=2R^3+(2R^2+r^2)\sqrt{R^2-r^2}. \tag{4}$$

We can plot equation (4) by putting $r/R=k$ and solving for R,

$$R=\frac{3k^2h}{2+(2+k^2)\sqrt{1-k^2}},\quad r=kR.$$

as parametric equations equivalent to (4).

Case 3—The water just comes to the top of the shell, $h=R+\sqrt{R^2-r^2}$ and equations (3) and (4) reduce to the same thing $r=\sqrt{3}R/2$ giving us

$$R=2h/3,\qquad r=h/\sqrt{3}. \tag{5}$$

If we take r and R as coördinates of the two curves, the curves (3) and (4) are tangent at this point as can be seen by finding dr/dR for each curve at this point. Hence equation (3) should be used for

$R \geqq 2h/3$ or $\sqrt{3}/2 \leqq k < 1$ and equation (4) for $0 < R \leqq 2h/3$ or $0 < k \leqq \sqrt{3}/2$. Thus if h is a constant, R can have all positive values and the ratio k ranges from 0 to 1.

It should be noticed that if R and r are fixed and h varied the ball would tend to rise for h less than the value given by (3) or (4) and would stay down for values of h greater than this value.

Also solved by PHILIP FITCH and H. B. WILCOX.

3125 [1925, 137]. **Proposed by W. J. Sidis, New York City**

If n is a prime number and r is a prime number not of the form $kn+1$, then in the scale of radix r, a perfect nth power can be found ending in any given digit. Also, provided the given last digit is not 0, a perfect nth power can be found ending in any given set of digits.

SOLUTION BY CONSTANCE R. BALLANTINE, New York University.

Let $x^n = a_0 + a_1 r + a_2 r^2 + \ldots$. Then if a_0 is given, the possibility of finding x depends on the possibility of solving the congruence

$$x^n \equiv a_0 \pmod{r}.$$

That the congruence can be solved, under the given conditions, follows at once from a theorem of Legendre (Dickson, *History of the Theory of Numbers* I, 205). The only solution is

$$x \equiv a_0^{l} \pmod{r}$$

where $ln - q(r-1) = 1$, the g. c. d. of n and $r-1$.

Suppose we have found $y_1, y_2, \ldots y_{k-1}$ such that

$$x \equiv a_0^{l} + y_1 r + y_2 r^2 + \ldots + y_{k-1} r^{k-1} \pmod{r^k}$$

implies

$$x^n \equiv a_0 + a_1 r + a_2 r^2 + \ldots + a_{k-1} r^{k-1} \pmod{r^k}. \tag{1}$$

Then we can find y_k such that

$$x \equiv a_0^{l} + y_1 r + y_2 r^2 + \ldots + y_{k-1} r^{k-1} + y_k r^k \pmod{r^{k+1}} \tag{2}$$

implies

$$x^n \equiv a_0 + a_1 r + a_2 r^2 + \ldots + a_{k-1} r^{k-1} + a_k r^k \pmod{r^{k+1}}. \tag{3}$$

For, raising (2) to the nth power, we shall have in view of (1)

$$x^n \equiv a_0 + a_1 r + \ldots + a_{k-1} r^{k-1} + (n a_0^{l(n-1)} y_k + b) r^k \pmod{r^{k+1}} \tag{4}$$

where

$$b = \Sigma \left(\frac{n!}{i_0! i_1! i_2! \ldots i_{k-1}!} \right) a_0^{l(n-i_0)} y_1^{n-i_1} y_2^{n-i_2} \ldots y_{k-1}^{n-i_{k-1}},$$

the summation extending over all $i_0, i_1, \ldots, i_{k-1}$ for which $i_1 + 2i_2 + \ldots + (k-1)i_{k-1} = k$, $i_0 + i_1 + \ldots + i_{k-1} = n$.

From (3) and (4) we obtain

$$n a_0^{l(n-1)} y_k r^k \equiv (a_k - b) r^k \pmod{r^{k+1}};$$

whence

$$n a_0^{l(n-1)} y_k \equiv a_k - b \pmod{r},$$

which is solvable if

$$a_0 \not\equiv 0 \pmod{r}.$$

3129 [1925, 204]. Proposed by C. N. Schmall, New York City.

Three hyperbolas are described each touching one side of a given triangle and having the remaining sides as asymptotes. Show that the product of their three latera recta is equal to the cube of the diameter of the inscribed circle of the triangle.

SOLUTION BY C. A. SHOOK, Yale University

Let ABC be any triangle with angles A, B, and C and sides a, b, and c. Choose rectangular axes with origin at A, x-axis bisecting the angle A, and such that C is in the first and B in the fourth quadrant. Then,

$$C\equiv(b\cos\frac{A}{2}\,,\ b\sin\frac{A}{2})\ \text{ and }\ B\equiv(c\cos\frac{A}{2}\,,\ -c\sin\frac{A}{2})$$

If $K=\dfrac{b-c}{b+c}$, the slope of BC is $\dfrac{1}{K}\tan\dfrac{A}{2}$,

and its equation is,

$$x\tan\frac{A}{2}-Ky=b\sin\frac{A}{2}(1-K)\,. \tag{1}$$

The hyperbola,

$$\frac{x^2}{\beta^2\cot^2\dfrac{A}{2}}-\frac{y^2}{\beta^2}=1\,, \tag{2}$$

will have AB and AC as asymptotes. We must determine β so that (2) is tangent to (1).

The slope of the hyperbola at any point is $(x/y)\tan^2 A/2$ so that at the point of tangency,

$$\frac{x}{y}\tan^2\frac{A}{2}=\frac{1}{k}\tan\frac{A}{2}$$

From (1) and (3), the point of tangency is found to be,

$$\left[\ \frac{1}{2}(b+c)\cos\frac{A}{2}\,,\ \frac{1}{2}(b-c)\sin\frac{A}{2}\ \right].$$

β is easily determined by substituting these co-ordinates in (2). There results $\beta=\sqrt{bc}\sin\dfrac{A}{2}$.

Now the latus rectum $=L_a=2\beta\tan\dfrac{A}{2}=2\sqrt{bc}\sin\dfrac{A}{2}\tan\dfrac{A}{2}$.

Calling r the radius of the inscribed circle and using the well-known values for $\sin A/2$ and $\tan A/2$,

$$L_a=\frac{2r\sqrt{(s-b)(s-c)}}{s-a}\,.$$

L_b and L_c are found by permuting a, b, and c.
Then $L_a\cdot L_b\cdot L_c=8r^3=(\text{diameter})^3$.

Also solved by LEONARD CARLITZ, MICHAEL GOLDBERGER, M. S. KNEBELMAN, and AUGUST SÖRENSON.

NOTES AND NEWS

Readers are invited to contribute to the general interest of this department by sending items to H. W. KUHN, Ohio State University, Columbus, Ohio.

At Miami University, Mr. E. E. ERICKSON of Iowa University has been appointed assistant professor. Assistant Professors R. A. SHEETS and G. W. SPENCELEY have been promoted to associate professorships. MRS. G. W. SPENCELEY is supplying for Professor Sheets who has been compelled by ill health to give up teaching for the year.

At Central Wesleyan College, Warrenton, o., Professor J. W. BLINCOE has been appointed head of the department of mathematics to succeed Professor H. V. KNORR who has resigned.

Professor W. W. RANKIN, head of the mathematics department at Agnes Scott College, Decatur, Ga., has been appointed to a professorship in Duke University and will begin work there next September.

Professor I. M. DELONG of the University of Colorado represented the Mathematical Association at the inauguration of President C. C. MIEROW at Colorado College on December 5, 1925.

Princeton University has received a gift of $150,000 from Mr. T. D. JONES, of Chicago, to be used to endow a chair in the department of mathematics to be called the Henry Burchard Fine professorship of mathematics, in honor of Professor FINE, dean of the department of science.

Dr. M. C. FOSTER, of Yale University, has been appointed assistant professor of mathematics at Williams College.

Dr. J. H. TAYLOR, of Princeton University has been appointed assistant professor of mathematics at Lehigh University.

Assistant Professor P. H. LINEHAN of the College of the City of New York has been promoted to an associate professorship of mathematics.

At Clark University, Professor F. B. WILLIAMS, professor of mathematics since 1908, will be absent on sabbatical leave for the second half of the current year. He will spend his time in Eurpoe. Mr. R. R. SMITH, A.B., at present instructor in mathematics at the Newton, Mass., High School, has been appointed assistant professor in mathematics and education.

Mr. R. L. FLANDERS, of Norwich University, has been appointed assistant professor of civil engineering at the Oklahoma Agricultural and Mechanical College.

Mr. L. C. BAGBY has been appointed assistant professor of mathematics at the University of South Dakota.

Professor W. P. YANCEY, profesor of mathematics and physics at St. Ambrose College, Davenport, Iowa, died on March 13, 1925. He held the degree of A.M. from Woodstock College, and had been in his position at St. Ambrose since 1918. He served also as vice-president of the Tri-City Chemist Club and as director of St. Ambrose Science Club.

Professor L. A. STOUT, for many years head of the department of mathematics in Dakota Wesleyan University, Mitchell, S. Dak., died Jan. 31, 1926.

Professor G. N. ARMSTRONG of Ohio Wesleyan University died January 7, 1926.

Professor M. T. Peed of Emory University, Oxford, Georgia, died August 28, 1925. His work at Emory extended over a period of thirty-six years. He was a member of the American Mathematical Society, the Mathematical Association and of the Phi Beta Kappa Society.

Mr. W. E. HEAL, of the U. S. Coast and Geodetic Survey, died October 9, 1925, at the age of 69.

The death is announced of Mr. G. P. ALDRICH, of the State University of Iowa.

Wells College is giving an honor course in mathematics for students of marked ability. During the two upper years the honor candidate has calculus, projective geometry, differential equations, higher plane curves and a seminar in which subjects are assigned for individual study and written reports. The examination at the end of the senior year covers all honor work in mathematics and is given by a committee of three consisting of two outside mathematicians and the head of the department of mathematics at Wells.

The Louisiana-Mississippi Section of the Association will hold its third annual meeting March 12 and March 13 at New Orleans under the auspices of Tulane University, Newcombe College, and the Academy of Science at New Orleans. Professor FLORIAN CAJORI of the University of California will be the guest of the Section on this occasion.

At the Louisiana State University, Professor S. T. SANDERS has just returned after an extended absence during which he has been studying at the University of Chicago. During his absence Professor I. C. NICHOLS has been in charge of the Department. The site of the University has recently been changed to a place two miles south of the city of Baton Rouge where ample grounds and new buildings provide a fine opportunity for the growth of the institution. Mr. RALPH O'QUIN, instructor in the Department, has spent several summers in graduate study at the University of Texas.

The Royal Academy of Belgium has awarded the prize for its 1925 mathematical competition to Professor W. C. GRAUSTEIN of the department of mathematics of Harvard for his memoir on the geometry of surfaces. The prize has been won by an American only once before, when, in 1909, it was awarded to Professor E. J. WILCZYNSKI of the University of Chicago. Professor Wilczynski has been seriously ill for more than two years. He is now at a private sanitarium in Denver, Colorado.

Anticipating the official announcement of the new Chauvenet Prize given by the Association for excellence in expository contributions in mathematics, which will appear in the Secretary's report of the Kansas City meeting, readers of the MONTHLY will be pleased to know that the first award for the period 1919-1924 was made to G. A. BLISS for his paper in the *Annals of Mathematics* last year on "Algebraic Functions and their Divisors." The hundred dollars in cash was provided for this first award by a friend of the Association, but will be appropriated from the Association treasury hereafter for each five-year period. It was felt by the donor and the members of the committee who determined the terms of award that such a prize would tend to stimulate expository production and that more such contributions are greatly needed.

The second number of the Carus Mathematical Monographs is now in press and will be ready for delivery early in February. This number is entitled *Analytic Functions of a Complex Variable* by Professor D. R. CURTISS of Northwestern University. It will be published in the same style as the first monograph and will have about the same size. It will be sold to members of the Association at the cost price of $1.25, one copy to each member who sends in his application for the same to the Secretary of the Association. The distribution to the public will take place as before through the OPEN COURT PUBLISHING Company and the regular sale price will be $2.00 per volume.

The distribution of the first monograph to the members of the Association has reached about 900. Other members who have not yet subscribed may still do so by making application to the Secretary. It would be a great tribute to the donor and a satisfaction to the officers of the Association, as well as a strong stimulus for the sales to the outside public, if practically every member should become a subscriber to the entire series of Carus monographs.

The National Council of Teachers of Mathematics has just published a *Yearbook* on the general theme: "Progress in the teaching of mathematics in the United States in the last twenty-five years." It contains contributions from D. E. SMITH, Columbia University, on "A general survey of mathematics in our high schools"; E. H. MOORE, on "The foundations of mathematics" (a

reprint of his presidential address); W. D. REEVE, Columbia University, on "Improving tests in mathematics"; RALEIGH SCHLORING, University of Michigan, on "Suggestions for the solution of an important problem"; FRANK CLAPP, University of Wisconsin, on "Some recent investigations in arithmetic"; WILLIAM BETZ, Rochester, N. Y., on "Mathematics of the junior high school"; H. E. SLAUGHT, University of Chicago, on "Mathematics and the public"; MARIE GUGLE and others, Columbus Schools, on "Some recreational values secured in our secondary schools through mathematical clubs"; E. W. SCHREIBER, Maywood, Ill., on "Mathematics books published in recent years for secondary schools and for teachers of mathematics."

The National Council has undertaken to perpetuate the work of the National Committee on Mathematical Requirements which latter was initiated and sponsored by the Mathematical Association of America. The publication of this *Yearbook* is a step in the fulfillment of this responsibility. It deserves the support of all who are interested in the field of secondary mathematics.

The *Yearbook* is a volume of 150 pages and will be sold at the cost price of $1.10, postpaid. Orders may be sent to C. M. AUSTIN, Oak Park High School, Oak Park, Ill. The edition is limited to two thousand copies.

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MEETINGS OF THE ASSOCIATION AND ITS SECTIONS

Tenth Summer Meeting of the Association, Columbus, Ohio, September 7-8, 1926.

Eleventh Annual Meeting, Philadelphia, Pa., December, 1926.

The following are dates of Section Meetings of the Association in 1926:

ILLINOIS, Decatur, Ill., May 7-8.

INDIANA, Purdue University, May.

IOWA, Cedar Rapids, April.

KANSAS, Combined with National Meeting, Kansas City, Mo.

KENTUCKY, Berea College, May 1.

LOUISIANA-MISSISSIPPI, New Orleans, La., March 12-13.

MARYLAND - DISTRICT OF COLUMBIA - VIRGINIA, Baltimore, Md., May 8

MICHIGAN, Ann Arbor, Mich., April 1.

MINNESOTA, Northfield, Minn., May 22.

MISSOURI, Kansas City, Mo., November.

NEBRASKA, Bethany, Neb., May.

OHIO, Columbus, Ohio, April 2.

ROCKY MOUNTAIN, Fort Collins, Colo., April 16-17.

SOUTHEASTERN, Atlanta, Ga., March.

SOUTHERN CALIFORNIA, Los Angeles, Calif., November 6.

TEXAS, Not yet determined.

Secretaries of Sections will please report changes or corrections promptly to the Editor.

THE MATHEMATICAL ASSOCIATION OF AMERICA

(INCORPORATED)

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* Removed from state. † Died Aug. 28, 1925.

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DE KALB. Parson.
EUREKA. Newson.
EVANSTON. O. E. Brown, D. F. Campbell, Curtis, Curtiss, Holgate, R. L. Jackson, E. J. Moulton, Newell, Simmons, Vass, E. M. Weaver, Westcott, F. E. Wood.
FREEPORT. Eichelberger, Mensenkamp.
GALESBURG. Calkins, Heren, Sellew, M. E. Taylor.
GREENVILLE. M. G. Smith.
JACKSONVILLE. M. Anderson, H. W. English, G. H. Scott.
LAKE FOREST. M. M. Johnson.
LA SALLE. Carus.
LEBANON. Stowell.
LINCOLN. Denny.
LISLE. Fleisig.
MACOMB. Ginnings.
MAYWOOD. Schreiber.
MONMOUTH. Winbigler.
MOUNT MORRIS. L. S. Shively.
NAPERVILLE. Coultrap.
NORMAL. C. N. Mills.
OAK PARK. Escott.
ORLEANS. J. T. Holmes.
PEORIA. Comstock, Gault.
RIVER FOREST. Dobbin.
ROCKFORD. McGavock, B. I. Miller.
ROCK ISLAND. Cederberg.
TAYLORVILLE. Dappert.
URBANA. B. M. Armstrong, Bender, C. C. Camp, R. D. Carmichael, Coble, Crathorne, Emch, Graesser, M. G. Haseman, Horne, F. E. Johnston, Libman, Lytle, R. M. Mathews, G. A. Miller, Mouzon, Reinsch, Steimley, Stetson, Townsend, A. L. Young.
WHEATON. Garlough.

INDIANA. (51)

BLOOMINGTON. H. T. Davis, Davisson, Hanna, Hennel, Rothrock, K. P. Williams, H. E. Wolfe.
COLUMBIA CITY. Knisely.
CRAWFORDSVILLE. Carscallen, Cragwall.
DANVILLE. L. R. Cole.
DUNKIRK. Clevenger.
EARLHAM. F. Long.
GOSHEN. Lehman.
GREENCASTLE. Arnold, Greenleaf.
HANOVER. G. E. Moore.
INDIANAPOLIS. Aley, Banes, Diederich, Edwards, E. N. Johnson, Lutz.
LAFAYETTE. Marshall, Mason.
NEW ALBANY. Donnelly.
NORTH MANCHESTER. Dotterer.
NOTRE DAME. Caparo, Hull, McCue, Maurus.
OAKLAND CITY. W. Jordan.
RICHMOND. E. D. Grant, H. N. Wright.
TERRE HAUTE. Kennedy, Sousley.
WADESVILLE. Blackburn.
WEST LAFAYETTE. Barr, J. C. Bennett, E. M. Berry, Bolks, Edington, Graves, Hadley, Hazard, Hodge, Knox, Nixon, Robbins, R. B. Stone, Zehring.

IOWA. (51)

AMES. Brandner, Colpitts, Daniells, Fleming, Gouwens, J. V. McKelvey, M. M. McKelvey, Pattengill, Roberts, Rogers, Sage, E. R. Smith, Snedecor, J. S. Turner.
CEDAR FALLS. Condit, Daugherty, Kearney.
CEDAR RAPIDS. L. M. Coffin, Yothers.
DES MOINES. Blom, Corey, Moon, Neff, Wifvat.
DUBUQUE. Theobald, Zimmerman.
FAYETTE. Deming.
GRINNELL. McClenon, Rusk.
HOPKINTON. Earhart.
INDIANOLA. C. W. Emmons.
IOWA CITY. Baker, Chittenden, Gwinn, C. A. Messick, Reilly, Rietz, Ward, W. H. Wilson, R. Woods, Wylie.
LE MARS. Kime.
MT. PLEASANT. King.
MOUNT VERNON. McGaw, Moots.
MUSCATINE. Stein.
OSKALOOSA. S. M. Hadley.
SIOUX CITY. Graber, Van Horne.
STORM LAKE. Reusser.
WELLMAN. Kreth.

KANSAS. (48)

BALDWIN CITY. P. L. Evans, Garrett.
COFFEYVILLE. Steininger.
EMPORIA. Philips, Rumney.
HAYS. Colyer.
HESSTON. Driver.
HIGHLAND. T. B. Henry.
IOLA. R. H. Carpenter, F. L. Marshall.
KANSAS CITY. Dougherty, Helwig.
LAWRENCE. Ashton, Babcock, Black, H. K. Hughes, H. E. Jordan, Marm, U. G. Mitchell, Reagan, G. W. Smith, Stouffer, H. M. Walker, J. J. Wheeler.
LINDSBORG. Lindberg.
MANHATTAN. W. H. Andrews, Holroyd, Hyde, Janes, C. F. Lewis, Lyons, Mossman, Remick, Stratton, A. E. White.
NEWTON. Richert.
OTTAWA. J. L. Bennett, Loewen.
PARSONS. Farner.
PITTSBURG. W. H. Hill, Shirk.
ST. MARYS. Case.
STERLING. T. Bell.
TOPEKA. Harshbarger, McLatchey.
WICHITA. Hoare, W. O. Mendenhall.
WINFIELD. H. S. Myers.

KENTUCKY. (21)

BEREA. Guilliams, Hutcherson, Peck.
DANVILLE. Crooks, Fehn.
GEORGETOWN. Clayton, C. H. Richardson.
LEXINGTON. Andrew, Boyd, M. E. Clarke, J. M. Davis, Downing, Le Stourgeon, Maney, E. L. Rees.
PARIS. R. I. Pepper, F. A. Scott.
RUSSELLVILLE. Saunders.
STANFORD. E. V. Watts.
VERSAILLES. Kienzle.
WILLIAMSBURG. Vallandingham.

LOUISIANA. (30)

ALEXANDRIA. Touchstone.
BATON ROUGE. Guilbeau, Nichols, O'Quinn, S. T. Sanders, Shoptaugh, Webber, Welch.
CLINTON. Petty.
ELTON. B. A. Tucker.
HOMER. Z. Allen.
LAFAYETTE. Stokes.
NATCHITOCHES. Maddox, Sparks.
NEW ORLEANS. H. E. Buchanan, Cope, Daly, Dinwiddie, A. M. Howe, Lastrapes, Latimer, Many, J. H. Meyer, Spencer.
PINEVILLE. C. D. Smith.
RUSTON. Pugh.
SHREVEPORT. Hardin, Maizlish.
VIVIAN. J. H. Manning.
ZACHARY. Peters.

MAINE. (9)

BRUNSWICK. Hammond, Moody.
LEWISTON. Ramsdell.
ORONO. Bryan, Hadlock, J. N. Hart.
WATERVILLE. Ashcraft, B. E. Carter, Trefethen.

MARYLAND. (49)

ANNAPOLIS. Bingley, Bramble, J. A. Bullard, Capron, Clements, Dillingham, Eppes, Garrison, Gaver, Mayer, Rawlins, Robert, Root, J. B. Scarborough, J. Tyler.
BALTIMORE. Bacon, H. Barton, Cary, Cohen, C. W. R. Crum, Harry, Hulburt, F. P. Lewis, F. Morley, Murnaghan, Musselman, C. A. Nelson, Rainich, L. J. Reed, Richeson, A. C. Robinson, Schad, Stanwick, Thomsen, Torrey, Wagner.
CHELTENHAM. Hartnell.
CHESTERTOWN. J. S. W. Jones.

CHEWSVILLE. Waltz.
COLLEGE PARK. Gwinner, Spann, Taliaferro.
EMMITSBURG. Burke.
FREDERICK. K. S. Arnold, L. O. Brown, Packer.
RIVERDALE. W. C. Myers.
ROLAND PARK. Morrow.
WESTMINSTER. B. I. Hart.

MASSACHUSETTS. (92)

AMHERST. Esty, F. C. Moore, Olds, C. S. Porter, W. R. Porter.
BELMONT. Douglass, Downey, Rutledge.
BOSTON. C. A. Benander, V. I. Benander, Brigham, Bruce, Gould, Laurentine, Mode, Osborne, M. M. Smith, Spear, Edwin B. Wilson.
BROOKLINE. A. L. Miller.
CAMBRIDGE. F. H. Bailey, Beatley, Birkhoff, Bradley, Coolidge, W. L. Crum, Franklin, Graustein, E. V. Huntington, Jenkins, M. F. Jordan, Kellogg, Kennelly, C. L. E. Moore, Osgood, Passano, F. W. Perkins, H. B. Phillips, L. H. Rice, H. W. Tyler, Walsh, D. E. Whitford, Winters, F. S. Woods, Zeldin.
CHESTNUT HILL. Archer.
DORCHESTER. Quigley.
EVERETT. Bryant.
HOLYOKE. Moriarty.
LAWRENCE. Lord.
LYNN. G. W. Evans.
MELROSE. Hussey.
NATICK. Willis.
NORTHAMPTON. S. R. Benedict, Eversull, Munroe, Rambo, R. G. Wood.
NORTON. G. A. Shook.
PITTSFIELD. Washburne.
SOUTH HADLEY. Doak, E. N. Martin, S. E. Smith.
SPRINGFIELD. Hickox, Marsh.
TUFTS COLLEGE. Bush, Mergendahl, Ransom.
VINEYARD HAVEN. H. M. Manning.
WELLESLEY. Anderton, Copeland, Merrill, C. E. Smith, Stark, Vivian, M. M. Young.
WEYMOUTH. Loud.
WILLIAMSTOWN. Agard, Hardy, V. H. Wells.
WOLLASTON. Dennison, Gardner.
WORCESTER. E. C. Brown, Gay, Hollis, Lazott, Melville, R. K. Morley, Phinney, H. Rice, A. H. Wheeler, F. B. Williams.

MICHIGAN. (65)

ALBION. F. E. Field, Sleight.
ALMA. Clack.
ANN ARBOR. Anning, Blessing, Bradshaw, Coe, Craig, Denton, Dostal, P. Field, S. E. Field, W. B. Ford, J. W. Glover, T. H. Hildebrandt, Hopkins, M. F. Johnson, Karpinski, Kazarinoff, Lemon, Love, Markley, O. J. Peterson, Poor, Raiford, C. Reid, Romig, Rood, Rouse, Running, Schorling, Shohat, Ziwet.
BAY CITY. Shellenberger.
DETROIT. Baldwin, Barlow, Darnell, Mullen, A. L. Nelson, Worden.
EAST LANSING. Crowe, L. C. Emmons, Evers, V. G. Grove, R. N. Haskell, H. L. Olson, Plant, Speeker.
HIGHLAND PARK. Thome.
HILLSDALE. Herron, Penrod.
HOLLAND. Lampen.
KALAMAZOO. H. Blair, J. P. Everett, T. O. Walton.
MARQUETTE. Spooner.
MONROE. Paula.
MOUNT PLEASANT. Pearce.
ROYAL OAK. Schoonover.
STURGIS. Steirnagle.
YPSILANTI. Barnhill, Gee, Lindquist, Lyman, Matteson.

MINNESOTA. (37)

COLLEGEVILLE. Winklemann.
DULUTH. Brigetta.
MANKATO. Chapman, A. V. Robbins.
MINNEAPOLIS. Beal, Brink, Brooke, Bussey, Dalaker, Earl, Gibbens, W. L. Hart, Hartig, D. Jackson, Kirchner, Priester, Shuman, Shumway, H. L. Smith, Sublette, Thorp, Underhill, Warne, Wilcox.
MOOREHEAD. K. Leonard.
NORTHFIELD. Clement, Gingrich, Nordgaard, M. B. White.
ST. CLOUD. Bemis.
ST. PAUL. R. A. Johnson, Kingery, Moench, Reuterdahl, F. J. Taylor.
VIRGINIA. C. L. Hancock.
WINONA. Bogard.

MISSISSIPPI. (13)

A. AND M. COLLEGE. H. Fox, B. M. Walker.
BLUE MOUNTAIN. Hutchins.
CLINTON. Hitt.
COLUMBUS. S. P. Walker.
GULFPORT. Maiden, Mauldin.
HATTIESBURG. Sharp.
JACKSON. Babbitt, Horrell, Smylie.
UNIVERSITY. Hume, R. Torrey.

MISSOURI. (39)

CAPE GIRARDEAU. B. F. Johnson, Knepper.
COLUMBIA. E. F. Allen, Callaway, Ingold, Jaeger, Wahlin, W. D. A. Westfall.
FULTON. Sweazey, M. A. Wood.
KANSAS CITY. Cutting, Epperson, Luby, Pierson.
KIRKSVILLE. Cosby, Jamison.
LIBERTY. Fleet.
PARKVILLE. R. A. Wells.
ROLLA. Hinsch.
SPRINGFIELD. Finkel, W. N. Thompson.
ST. CHARLES. Karr.
ST. LOUIS. Ammerman, Brennan, Dunkel, Gerst, A. H. Huntington, E. W. King, Nauer, Osborn, Rider, Roever, Shannon, E. Stephens, J. M. Young.
TARKIO. Jenison.
WARRENSBURG. J. H. Scarborough.
WARRENTON. Knorr.
WEBSTER GROVES. M. B. Clarke.

MONTANA. (5)

GLASGOW. Calderwood.
HELENA. O'Neill.
MISSOULA. Carey, Lennes, A. S. Merrill.

NEBRASKA. (22)

BETHANY. Osterhout.
CERESCO. L. C. Walker.
CRETE. J. N. Bennett.
GRAND ISLAND. H. Anderson.
HASTINGS. McDill.
KEARNEY. Hanthorn.
LINCOLN. Brenke, Candy, Congdon, Gaba, M. F. Jackson, Kirker, Opp, T. A. Pierce, Runge.
OMAHA. H. A. Campbell, Frankish, T. I. Porter, Wilmer.
PERU. A. L. Hill.
UNIVERSITY PLACE. Howie.
YORK. Feemster.

NEVADA. (1)

RENO. C. Haseman.

NEW HAMPSHIRE. (14)

DOVER. Huntley.
DURHAM. G. N. Bauer, Slobin, Wilbur.
EXETER. Sweet.
HANOVER. Beetle, Bill, B. H. Brown, C. H. Forsyth, Mathewson, Morgan, Silverman, C. E. Wilder, J. W. Young.

NEW JERSEY. (35)

BELLEPLAIN. Durell.
CARTERET. G. H. Hill.
CONVENT STATION. Maskell.
CRAWFORD. Knedler.
EAST ORANGE. Koch, Mallory, F. H. Robinson.
JERSEY CITY. J. P. Smith.
LAMBERTVILLE. Okean.
LEONIA. Gafafer, M. S. Taylor.
MOONESTOWN. R. R. Wood.
MORRIS PLAINS. A. E. Johnson.
NEWARK. Conkling.
NEW BRUNSWICK. Carlson, Dresser, Garretson, R. Morris, R. Thompson, A. A. Titsworth.
PATERSON. Caster.
PRINCETON. E. P. Adams, Alexander, Eisenhart, Fine, W. Gillespie, Hille, Lefschetz, H. D. Thompson, Veblen, Wedderburn, Willson.
RUTHERFORD. McMackin.
SUMMIT. H. E. Webb.
TRENTON. Colliton.

NEW MEXICO. (4)

ALBUQUERQUE. Barnhart.
EAST LAS VEGAS. Rodgers.
SILVER CITY. Hunter.
SOCORRO. Reece.

NEW YORK. (182)

ALBANY. Birchenough, G. M. Conwell.
ALFRED. Seidlin, W. A. Titsworth.
ANNANDALE-ON-HUDSON. Packard.
AURORA. Hollcroft.
BALDWIN. C. C. Grove.
BEECHHURST. E. Berger.
BROOKLYN. Angelica, Bergstresser, W. J. Berry, Bowden, Emery, Kreines, Langman, Lehmann, Littauer, Locke, Rosanoff, Schuyler, Tanzola, Thecla, G. F. Wilder.
BUFFALO. Cusick, Harrington, T. H. Milne, Pound, Sherk.
CLINTON. H. S. Brown, Carruth, Ferry, A. L. Fitch.
DE KALB JUNCTION. H. M. Phillips.
EAST ELMHURST. Hanson.
ELMIRA. Suffa, F. W. Wright.
FLUSHING. P. H. Graham, Oglesby.
GENEVA. W. H. Durfee, W. P. Durfee, Hubbs.
HAMILTON. Aude, DoBell, A. W. Smith.
ITHACA. Agnew, Beisel, Boothroyd, Carver, Farnum, D. C. Gillespie, Hurwitz, B. F. Kimball, MacCreadie, H. B. Meek, F. W. Owens, H. B. Owens, Poritsky, Ranum, Schoonmaker, Shaub, V. Snyder, Tanner, Wiener.
JACKSON HEIGHTS. Harper.
LARCHMONT. Hekimian.
MOUNT VERNON. Breckenridge.
NEWBURGH. C. W. Miller.
NEW YORK. J. Allen, Auerbach, Autenrieth, Ballantine, Berkeley, V. Blair, W. M. Bond, Brahdy, Brewster, T. H. Brown, Burdick, R. W. Burgess, G. A. Campbell, Chellborg, J. R. Clark, R. F. Clark, J. G. Coffin, Cooley, C. H. Douglas, Eckersley, Edmonson, Eisele, Fiske, Fite Fort, Foster, Frankel, Fry. Hawkes, R. Henderson, Himwich, Hirsch, Hodgdon, Hoyt, Jablonower, Joffe, Kasner, Kunte, Langellotti, Larkin, Linehan, J. J. McCarthy, McGuire, Meder, Mirick, Molina, A. I. Moore, Mullins, Paaswell, Pedersen, Penn, Phelps, Pooler, Post, Pride, Quilty, Reddick, Reeve, Ritt, Saurel, Schmall, Schub, Seto, Shewhart, Siceloff, Simons, D. E. Smith, R. F. Smith, R. R. Smith, Spies, W. A. Stevens, H. Thompson, Thorne, Tilly, A. B. Turner, Upton, Waldo, E. Walker, Webster, Wechsler, E. E. Whitford, W. O. Wiley, Woodyard.
OLEAN. S. L. Fitch, Lowry.
PARISH. Church.
PLEASANTVILLE. B. G. Westfall.
POUGHKEEPSIE. Cowley, Cummings, M. E. Wells.
ROCHESTER. Betz, Gale, H. Harding, T. R. Long, Silberstein, Watkeys, Weisner.
SCARSDALE. MacNeish.
SCHENECTADY. D. S. Morse, Newkirk, A. D. Snyder, Vedder.
SYRACUSE. W. G. Bullard, Carroll, Decker, Lindsey, Secy. Pi Mu Epsilon Frat., Roe, M. Sperry, W. E. Taylor.
TARRYTOWN. R. G. Putnam.
TROY. Crockett.
WEST POINT. C. P. Echols.
YONKERS. Hubert, F. W. John, Yanosik.

NORTH CAROLINA. (19)

CHAPEL HILL. Browne, Cain, A. Henderson, M. A. Hill, Hobbs, Lasley.
CHARLOTTE. O. M. Jones.
DAVIDSON. J. L. Douglas.
DURHAM. M. R. Richardson, Robison.
ELON COLLEGE. Amick.
GREENSBORO. G. W. Mendenhall, F. S. Mitchell, Pegram, Strong.
GREENVILLE. M. D. Graham.
GUILFORD COLLEGE. Pancoast.
JAMESTOWN. Ragsdale.
MURFREESBORO. Caldwell.

NORTH DAKOTA. (5)

FARGO. Householder, I. W. Smith.
MINOT. De La.
UNIVERSITY. Hitchcock.
VALLEY CITY. J. B. Meyer.

OHIO. (99)

ADA. Fairchild, Whitted.
AKRON. P. C. Jones.
ALLIANCE. Trott.
ATHENS. Borger, F. W. Reed.
BEREA. Dustheimer.
BOWLING GREEN. Overman.
BLUFFTON. Hirschler.
CHILLICOTHE. Cornetet.
CINCINNATI. I. A. Barnett, Brand, Garabedian, H. Hancock. Kindle, Lubin, C. N. Moore, Salkover, E. S. Smith, Wilczewski, Yowell.
CLEVELAND. Focke, W. W. Johnson, B. W. Jones, McBane, J. E. Merrill, M. Morris, Nassau, Palmié, Simon, C. F. Thomas, Wilkins.
COLUMBUS. C. L. Arnold, Atwater, Bareis, Blumberg, Bohannan, Cottingham, Harmount, R. S. Kimball, Kuhn, MacDuffee, McCoy, Manson, C. C. Morris, Preston, Rasor, Rickard, B. Sanders, Singer, R. L. Wilder, Wildermuth.
DAYTON. Hartwick.
DEFIANCE. A. G. Caris.
DELAWARE. G. N. Armstrong, Crane, R. L. Newlin.
GAMBIER. R. B. Allen, Denston.
GRANVILLE. F. B. Wiley.
HARRIETTSVILLE. G. S. Jones.
HILLIARD. J. H. Weaver.
HIRAM. E. H. Clarke, Jerome.
KENT. Manchester.
MARIETTA. Coar, Rea.
NEW CONCORD. C. E. White.
OBERLIN. Cairns, Carr, A. H. Fox, Sinclair, Yeaton.
OXFORD. J. P. Albert, W. E. Anderson, Baudin, M. B. Carter, Lange, Sheets, Spenceley, Tappan.
PAINESVILLE. A. D. Lewis.
Ross. Haldeman.
SPRINGFIELD. Tripp.
STEUBENVILLE. Horn.
TIFFIN. J. Pierce, Rhodes.
TOLEDO. Brandeberry, Dancer, Mercedes.
URBANA. Stout.
WASHINGTON C. H. Haigler.
WESTERVILLE. B. C. Glover.
WILBERFORCE. Tinner, Waits.
WILMINGTON. Spinks.
WOOSTER. Williamson, Yanney.
ZANESVILLE. Riesbeck.

OKLAHOMA. (22)

ALVA. H. L. Hall.
CHICKASHA. Hawkins.
DURANT. Work.
MIAMI. J. B. Steed, C. S. Whitney.
NORMAN. Court, Barbour, Hassler, D. McFarland, McGilvray, Meacham, S. W. Reaves, F. M. Wright.
OKLAHOMA CITY. Meador, L. V. Robinson.
SHAWNEE. W. T. Short.
STILLWATER. R. L. Flanders, Gundersen.
TULSA. Roman, G. R. West.
WEATHERFORD. McCormick.
WILSON. R. O. Webb.

OREGON. (11)

CORVALLIS. Beaty, C. L. Johnson, Van Fleet, G. A. Williams.
EUGENE. De Cou, McAlister, W. E. Milne, Wills.
PORTLAND. Griffin, Merriss, J. M. Short.

PENNSYLVANIA. (104)

ALLENTOWN. C. S. Allen, Bauman.
ANNVILLE. Redditt.
BEAVER FALLS. Cleland.
BETHLEHEM. A. A. Bennett, Knebelman, Lyle, McDonough, Rau, J. B. Reynolds, Weida.
BRYN MAWR. A. P. Wheeler, S. M. Wolfe.
CAMP HILL. Foberg.
CARLISLE. Landis.
COLLEGEVILLE. Clawson.
CRAFTON. B. C. Patterson.
CYNWYD. Sensenig.
DERRY. Minister.
DEVON. J. A. Clarke.
EASTON. Benner, Doushkess, W. S. Hall, Hatch, Marquard, W. M. Smith.
EDINBORO. Heinaman.
GERMANTOWN. Mullikin.
GETTYSBURG. Arms, Uhler.
GROVE CITY. Ramsey.
HARRISBURG. Whited.
HAVERFORD. L. W. Reid, A. H. Wilson.
HUNTINGTON. C. S. Shively.
IRWIN. A. A. Jones.
LANCASTER. R. L. Charles, W. F. Long.
LANSDOWNE. Chambers, Glenn, Gummere.
LATROBE. Seubert.
LEWISBURG. Bartol, H. S. Everett, Gold, Lindemann.
LINCOLN UNIVERSITY. W. L. Wright.
LOCK HAVEN. High.
MEADVILLE. Akers, Wagner.
MECHANICSBURG. N. B. Freeman.

MILLERSVILLE. Seiverling.
NEW WILMINGTON. McCain.
PARKESBURG. Lufkin.
PHILADELPHIA. W. L. Ayres, P. A. Caris, Crawley, Eshleman, H. B. Evans, F. H. Jackson, F. John, Kline, Levita, Linton, Partridge, Rittenhouse, Rosengarten, Safford, Shippy.
PITTSBURGH. Baird, Barrett, Bishop, Burley, Geckeler, R. P. Johnson, J. H. Mathews, Riggs, Rosenbach, Simester, Swartzel, Taber, J. S. Taylor, Whitman.
SLIPPERY ROCK. Lady.
SOUTH BETHLEHEM. MacNutt.
SHIPPENSBURG. Kieffer.
STATE COLLEGE. Bushyager, T. Cohen, J. E. Davis, Gravatt, L. S. Johnston, E. D. McCarthy, Shibli, J. M. West, F. G. Williams.
SWARTHMORE. Marriott, J. A. Miller.
SWISSVALE. Foraker.
WASHINGTON. Atchison, Bert, Cardin, R. W. Thomas.
WEST PHILADELPHIA. Latshaw.

PHILIPPINE ISLANDS. (4)

LAGUNA. Salvosa.
MANILA. Gokhale, Tan, Tienzo.

PORTO RICO. (1)

MAYAGUEZ. Sanchez.

RHODE ISLAND. (14)

NEWPORT. Chase.
PROVIDENCE. C. R. Adams, Archibald, Burwell, Chace, Currier, Gilman, Hickson, H. P. Manning, M. Morse, R. G. D. Richardson, Sauté, Suesman, Watt.

SOUTH CAROLINA. (13)

CHARLESTON. O. J. Bond, R. H. Coleman.
COLUMBIA. Coker, J. B. Coleman, J. B. Jackson, W. L. Williams.
GREENVILLE. Earle, R. B. Wood.
GREENWOOD. Weber.
HARTSVILLE. C. M. Reaves.
ROCK HILL. Pope, G. T. Pugh.
SALUDA. Ramage.

SOUTH DAKOTA. (9)

ABERDEEN. Hobart.
BROOKINGS. I. L. Miller.
HURON. Titt.
RAPID CITY. Bowles, McLaury.
STURGIS. Horlocker.
VERMILION. Bagby, McKinney.
YANKTON. Faught.

TENNESSEE. (13)

JACKSON. Hess, Walden.
KNOXVILLE. J. D. Bond, Brezler, Ghormley.
MARYVILLE. Knapp.
NASHVILLE. R. V. Blair, S. I. Jones, Miser.
NORMAL. P. L. Armstrong.
PULASKI. Mize.
RIPLEY. Edward B. Wilson.
SEWANEE. S. M. Barton.

TEXAS. (83)

ABILENE. Burnam.
AUSTIN. Batchelder, H. Y. Benedict, Cooper, Decherd, Dodd, Duncan, Ettlinger, Gehman, H. L. Holmes, Horton, Jacobs, Lubben, Mayne, D. E. Mitchell, R. L. Moore, Mullings, Phenix, M. B. Porter, P. K. Rees, W. A. Rees, Rupp, Rutherford, Smail, Vandiver.
BEAUMONT. M. A. Campbell.
BOERNE. Hathaway.
BROWNSVILLE. de la Garza.
BROWNWOOD. Gayden, McClelland.
CAMERON. Newton.
CANYON. L. G. Allen.
COLLEGE STATION. F. Ayres, A. A. Blumberg, H. A. Foster, Halperin, D. C. Jones, McKee, W. L. Porter, W. P. Stevens.
DALLAS. Dice, Hartsfield, E. H. Jones, Mahoney, Seale.
DENTON. M. C. Brown.
FORT WORTH. Hargett, Howard, E. R. Tucker.
GALVESTON. P. H. Underwood.
GEORGETOWN. Wunder.
HOUSTON. Bray, Dean, G. C. Evans, Ewing, L. R. Ford, Hickey, E. O. Lovett, Michal, Roos.
KINGSVILLE. H. Porter.
LUBBOCK. Ames, D. A. Flanders, E. T. Stafford, Whyburn.
MILFORD. Durham.
NACOGDOCHES. C. E. Ferguson.
PORT ARTHUR. G. S. Smith.
SAN ANTONIO. McNelly, J. E. Nelson, Roach, Rockwell.
SAN MARCOS. J. S. Brown, Kaderli, Sewell.
SHERMAN. May.
STEPHENVILLE. Hale, McSweeny, Marrs, Redden.
WACO. Harrell, W. A. Nelson.
WICHITA FALLS. B. T. Adams.

UTAH. (6)

LEWISTON. Van Orden.
SALT LAKE CITY. J. L. Gibson, Horsfall, Marthakis, Pehrson, Unseld.

VERMONT. (7)

BURLINGTON. Butterfield, Donahue, Millington, Swift, E. Thomas.
MIDDLEBURY. Hazeltine, L. R. Perkins.

VIRGINIA. (33)

ABINGDON. V. L. Wright.
ASHLAND. T. McN. Simpson.
BLACKSBURG. Brodie, Gudheim, Hatcher, O'Shaughnessy, J. E. Williams.
BRIDGEWATER. Shull.
CHARLOTTESVILLE. F. A. Wells.
CLIFTON STATION. O. Stone.
EMORY. J. S. Miller.
FARMVILLE. Taliaferro.
HOLLINS. Dickinson.
LANGLEY FIELD. Hemke.
LEXINGTON. Paxton, L. W. Smith, C. W. Watts, Witt.

LYNCHBURG. Larew, Pattillo.
MONTEREY. Colaw.
RADFORD. Bowers.
RICHMOND COLLEGE. Gaines.
SALEM. Carpenter.
SWEET BRIAR. Morenus, Searle.
UNIVERSITY. W. H. Echols, Luck, Sparrow, Thornton.
UNIVERSITY OF RICHMOND. I. Harris.
WILLIAMSBURG. Rowe, B. Russell.

WASHINGTON. (18)

DAVENPORT. P. A. Carlson.
EVERETT. Robb.
PULLMAN. G. H. Freeman, A. A. Grant, Isaacs.
SEATTLE. E. T. Bell, Biggerstaff, Caffrey, Cramlet, Jerbert, Moritz, Mullemeister, Neikirk, E. D. West, Winger.
TACOMA. Hanawalt.
WALLA WALLA. Bratton, Eells.

WEST VIRGINIA. (11)

BETHANY. Cramblet.
BRIDGEPORT. Slawter.
HUNTINGTON. Hackney.
INSTITUTE. Cox.
KEYSER. Harshbarger.
MORGANTOWN. M. Buchanan, Colwell, H. A. Davis, Eiesland, C. N. Reynolds, B. M. Turner.

WISCONSIN. (35)

BELOIT. H. H. Conwell, Huffer.
JANESVILLE. Battig.
MADISON. F. E. Allen, Bunyan, Dowling, Dresden, Fowlkes, W. W. Hart, Ingraham, Mickelson, E. B. Miller, Pollard, Skinner, Slichter, Van Vleck, W. Weaver.,
MILTON. A. E. Whitford.
MILWAUKEE. E. R. Beckwith, Ericson, P. H. Evans, Frumveller, Knight, Morrissy, Quarles, C. G. Simpson.
PLATTEVILLE. N. M. Johnston, Warner.
RIPON. Woodmansee.
RIVER FALLS. McMillan.
SOUTH MILWAUKEE. Hoar.
SUPERIOR. C. W. Smith.
WEST ALLIS. Roth.
WEST DE PERE. DeCleene.
WILLIAMS BAY. Justin.

WYOMING. (4)

LARAMIE. Bellamy, Fitterer, Gossard, Rechard.

FOREIGN MEMBERS. (Other than Canada.)

ARGENTINE. (1)

BUENOS AIRES. Baidaff.

BELGIUM. (1)

LIEGE. Van Hee.

BULGARIA. (1)

LOVETCH. E. M. Perry.

CHINA. (7)

CANTON. W. E. MacDonald.
CHANGSHA. Leavens.
NANKING. Loh.
PEKING. Heinz, Konantz.
SHANGHAI. Ely.
TANGSHAN. Patten.

FRANCE. (6)

BESANÇON. Lebeuf.
NANCY. Gérardin.
PARIS. Borel, Hadamard.
STRASBOURG. Fréchet, Linfield.

GERMANY. (1)

GÖTTINGEN. Coates.

GREAT BRITAIN. (5)

CAMBRIDGE. P. W. Wood.
EDINBURGH. Horsburgh.
HOVE. Chepmell.
OXFORD. Hardy, W. E. Robertson.

INDIA. (2)

ALLAHABAD CITY. Mitra.
CALCUTTA. Bose.

ITALY. (6)

BOLOGNA. Bortolotti, Enriques, Pincherle.
PALERMO. Cipolla.
PISA. Bianchi.
TURIN. Fubini.

JAPAN. (3)

PYENGYANG. Parker.
TOKYO. Mikami, Ono.

NEW ZEALAND. (1)

DUNEDIN. Martyn.

POLAND. (1)

WARSAW. Dickstein.

PORTUGAL. (1)

LISBON. da Cunha.

SOUTH AFRICA. (3)

BLOEMFONTEIN. Arndt.
JOHANNESBURG. Dalton.
RONDEBOSCH. Muir.

SPAIN. (1)

MADRID. de Toledo.

SWITZERLAND. (3)

FRIBOURG. Bays.
GENEVA. Fehr.
NEUCHATEL. DuPasquier.

SYRIA. (1)

BEIRUT. Jurdak.

TURKEY. (3)

CONSTANTINOPLE. A. F. Johnson, Mourad, Plapp.

UKRAINE. (1)

KIEFF. Kryloff.

RECAPITULATION OF MEMBERSHIP.

Individual members November 15, 1925	1,759	
Institutional members November 15, 1925	115	
Total membership November 15, 1925		1,874
Total membership November 1, 1922		1,476

CHARTER MEMBERSHIP.

Individual charter members	1,045	
Institutional charter members	52	
Total charter membership		1,097
Net gain in individual members	714	
Net gain in institutional members	63	
Total net gain over charter membership		777
Total net gain since November 1, 1922		398

BY-LAWS OF THE MATHEMATICAL ASSOCIATION OF AMERICA (INCORPORATED).

ARTICLE I—NAME, PURPOSE AND CORPORATE SEAL.

1. This organization shall be known as

THE MATHEMATICAL ASSOCIATION OF AMERICA (INCORPORATED).

2. Its object shall be to assist in promoting the interests of mathematics in America, especially in the collegiate field, by holding meetings in any part of the United States or Canada for the presentation and discussion of mathematical papers, by the publication of mathematical papers, journals, books, monographs and reports, by conducting investigations for the purpose of improving the teaching of mathematics, by accumulating a mathematical library and by coöperating with other organizations whenever this may be desirable for attaining these or similar objects.

3. The Corporate Seal of the Association shall have inscribed thereon the name of the Association and the words "Corporate Seal—Illinois."

ARTICLE II—MEMBERSHIP.

1. Any person who is interested in the field of collegiate mathematics shall be eligible for election to membership in the Association.

2. Any institution in which the Calculus is regularly taught shall be eligible for election to institutional membership in the Association. Such an institution shall have the privilege of sending a voting delegate to the meetings of the Association.

3. Election to membership shall be by vote of the Board upon written application from the individual or institution seeking admission, endorsed in the case of individuals by two members of the Association.

4. Those who were admitted to membership in The Mathematical Association of America (unincorporated) prior to October 1, 1920, and were in good standing as such on that date, were thereby admitted to membership in this Association (Incorporated).

ARTICLE III—BOARD OF TRUSTEES AND OFFICERS.

1. The Officers of the Association shall be a President, two (2) Vice-Presidents, a Secretary Treasurer, a Librarian and three (3) members of a Committee on Official Journal.

2. The control and management of the affairs and funds of the Association shall be vested in a Board of twenty (20) Trustees (hereinafter called the "Board"), who shall be members of the Association. This Board shall consist of the officers of the Association and twelve (12) additional members.

3. The President and Vice-Presidents shall be elected by the Association's members annually for a term of one year, and four members of the Board shall be elected by the Association's members annually for a term of three years. They shall be eligible for reëlection, but not for more than two (2) consecutive terms. The Secretary-Treasurer, the Librarian, and the Committee on Official Journal, consisting of the Editor-in-Chief, the Manager and one other member, shall be appointed by the Board. All Officers and other Trustees shall hold over until their respective successors are elected or appointed and qualify.

4. The Board shall transact the official business of the Association and shall report its actions at the annual business meeting of the Association and in the official journal. A statement regarding any proposed action of the Board which makes or alters a question of policy shall be published in the official journal, or notice of such proposed action shall be mailed to each member, before final action has been taken, so that members of the Association may make known to the Board their individual views.

5. The Board shall have authority to fill vacancies *ad interim* in any office, including vacancies in the Board and in the Committee on Official Journal, and to make any other appointments necessary for the transaction of the business of the Association.

6. At all meetings of the Board of Trustees a quorum shall consist of not less than five (5) members and no business may be validly transacted at a meeting at which less than a quorum is present; *provided* that any meeting of the Board, whether or not a quorum be present, may be adjourned to a specified time and place by a majority of the members present without notice to the members at large other than announcement at such meeting. Informal action based on a mail ballot by the members of the Board, if ratified at a properly convened meeting of the Board, shall be as valid and effective as if originally authorized at such meeting.

7. Approximately two months before the date of the annual meeting all members shall be given an opportunity to nominate by mail a candidate for each office to be filled by the members for the ensuing year. Approximately one month before the annual meeting the Board shall

announce two candidates for each office to be filled by the members, one being the person who received the highest vote in the nominations and the other being selected from among the several nominees next in order. The election shall be by mail or in person and shall close on the day of the annual meeting.

8. The President shall be the Executive Officer of the Association, shall preside at all meetings of the Board of Trustees and at the annual meeting of the Association. He shall have the usual duties pertaining to his office and such other duties as may from time to time be assigned him by the Board of Trustees.

9. The Vice-Presidents shall, in the absence of the President, have and exercise the powers of the President, their order being determined alphabetically. The Board of Trustees may assign to the Vice-Presidents such duties as may from time to time be determined.

10. The Secretary-Treasurer shall have the usual duties pertaining to the Office of Secretary and of Treasurer, including the custody of the records of the Association and of its Corporate Seal, the keeping of minutes of the meetings of the Board of Trustees and of the annual meeting and special meetings of members, and giving of due notice of all regular and special meetings of the Association and of the Board of Trustees and the supervision and safe-keeping of the funds of the Association. The Secretary-Treasurer shall also have the duty of seeing that whenever Trustees are elected, including the election of Trustees to fill vacancies, a Certificate, under the Seal of the Association, giving the names of those elected and the term of their office, shall be recorded in the Office of the Recorder of Deeds for Cook County, Illinois. Such Certificate shall be signed by the Secretary-Treasurer and verified by oath of the President.

11. The Committee on Official Journal shall have supervision of the official journal subject to the control of the Board of Trustees.

12. The Librarian shall have general charge of the library of the Association and shall direct its affairs, including the exchange of the publications of the Association, subject to the control of the Board.

Article IV—Meetings.

1. A meeting of the Association shall be held annually, at such time and place as the Board may direct. Special meetings of the Association may be called from time to time by the Board, or while the Board is not in session by the President of the Association, to be held at such time and place as may appear from the call.

2. The outgoing Board shall hold a meeting immediately preceding the annual meeting of the Association next succeeding their election, and the members of the new Board shall hold a meeting and organize, by completing the Board, immediately succeeding the annual meeting of the Association at which the new members thereof were elected. Further meetings of the Board may be held from time to time at the call of the President or of any three (3) members of the Board.

3. Notice of any meeting of members of the Association shall be given by the Secretary-Treasurer at least thirty (30) days prior to the date set for each meeting. Notice of all meetings of the Board other than the regular meetings provided in Section 2 shall be given to each member of the Board at least fifteen (15) days prior to the date set therefor.

4. Any member of the Association or of the Board may waive notice with the same effect as if due notice had been given him.

5. At all meetings of the Association a quorum shall consist of not less than twenty-five (25) members and no business may be validly transacted at a meeting at which less than a quorum is present; *provided* that any meeting of the Association, whether or not a quorum be present, may be adjourned to a specified time and place by a majority of the members present without notice to the members at large other than the announcement at such meeting.

6. Members may take part and vote in person or by proxy at all meetings of the Association.

Article V—Sections.

1. Any group of not less than ten (10) members of this Association may petition the Board for authority to organize a Section of the Association for the purpose of holding local meetings. The Board shall have power to specify the conditions under which such authority shall be granted.

2. The Association shall not be obligated to pay from its treasury any of the expenses of such Sections.

Article VI—Official Publications.

1. The Association shall publish an official journal, which shall be sent free to all members of the Association in accordance with Article VII.

2. The Board shall have full control of the publication and sale of the official journal and of all other official publications.

3. The official journal shall be under the general management of the Committee on Official Journal. There shall also be appointed by the Board a body of Associate Editors who shall give assistance in connection with the official journal and under the direction of the Committee on Official Journal.

4. The Board shall from time to time, as the need arises, make special provision for the management of any other official publications.

5. The Board shall fix the price of the official journal and of any other official publications of the Association, but in no case shall the journal be sold to non-members for less than the annual dues of individual members.

Article VII—Dues.

1. Individual members of the Association shall pay an initiation fee of Two Dollars ($2) at the time of election.

2. The annual dues of each individual member shall be Four Dollars ($4), including a subscription to the official journal.

3. The annual dues of each institutional member shall be Seven Dollars ($7), including two (2) subscriptions to the official journal.

4. All dues shall be payable on the first of January of each year. Should the annual dues of any member remain unpaid beyond a reasonable time, his name shall be dropped from the list after due notice.

5. New members entering the Association after April 1 of any year shall have their dues prorated for the balance of the year, except when they desire to receive the full current volume of the official journal.

6. The life membership fee shall be the present value, according to McClintock's Male Annuitant Table based upon four (4) per cent interest, of an annuity due of Four Dollars ($4) a year at the attained age of the member; an annual valuation of the life membership fund shall be made under the McClintock Male Four (4) Per Cent Table; and the reserve thus computed shall be held as a liability.

Article VIII—Amendments to the Articles of Association and By-Laws.

1. Changes in the Articles of Association or amendments to the By-Laws may be made at any annual meeting of the Association, or at any adjourned session thereof, or at any special meeting of the Association called for such purpose, by a two-thirds ($\frac{2}{3}$) vote of those present and entitled to vote; *provided* that due notice concerning such amendment shall have been printed in the official journal, or mailed to each member, at least one (1) month before the date of such meeting.

2. No changes in the Articles of Association shall have legal effect until a certificate thereof, verified by oath of the President and under Seal of the Association, attested by the Secretary-Treasurer, shall be filed in the office of the Secretary of State of the State of Illinois and recorded in the office of the Recorder of Deeds for Cook County, Illinois.

PERIODS OF SERVICE OF THE OFFICERS OF THE ASSOCIATION.

PRESIDENTS.

E. R. HEDRICK 1916
FLORIAN CAJORI 1917
E. V. HUNTINGTON 1918
H. E. SLAUGHT 1919
D. E. SMITH 1920
G. A. MILLER 1921
R. C. ARCHIBALD 1922
R. D. CARMICHAEL 1923
H. L. RIETZ 1924
J. L. COOLIDGE 1925

VICE-PRESIDENTS.

E. V. HUNTINGTON 1916
G. A. MILLER 1916
D. N. LEHMER 1917, 1918
OSWALD VEBLEN 1917
J. W. YOUNG 1918
R. G. D. RICHARDSON 1919
H. L. RIETZ 1919
HELEN A. MERRILL 1920
E. J. WILCZYNSKI 1920
R. C. ARCHIBALD 1921
R. D. CARMICHAEL 1921, 1922
B. F. FINKEL 1922
A. B. CHACE 1923
L. P. EISENHART 1923
J. L. COOLIDGE 1924
DUNHAM JACKSON 1924, 1925
A. A. BENNETT 1925

SECRETARY-TREASURER.

(Appointed by the Council or Board after 1918.)

W. D. CAIRNS 1916–

COMMITTEE ON PUBLICATIONS.

(Appointed by the Council or Board.)

H. E. SLAUGHT 1916–
R. D. CARMICHAEL 1916–1918
W. H. BUSSEY 1916–1918
R. C. ARCHIBALD 1919–1921
W. A. HURWITZ 1919–1921
A. A. BENNETT 1922
H. P. MANNING 1922
W. B. FORD 1923–
J. L. COOLIDGE 1923
A. J. KEMPNER 1924–

ELECTED MEMBERS OF THE COUNCIL OR BOARD.

D. N. LEHMER 1916–1918, 1922–
R. E. MORITZ 1916–1918
K. D. SWARTZEL 1916
OSWALD VEBLEN 1916, 1920–1922
R. C. ARCHIBALD 1916–1917, 1923–
FLORIAN CAJORI 1916, 1918–1923
M. B. PORTER 1916–1917
J. W. YOUNG 1916–1917, 1920–1922
B. F. FINKEL 1916–1921
E. H. MOORE 1916–1921, 1923–
J. N. VAN DER VRIES 1916–1918
ALEXANDER ZIWET 1916–1918
E. R. HEDRICK 1917–1922, 1924–
HELEN A. MERRILL 1917–1919
D. E. SMITH 1917–1919, 1921–
ELIZABETH B. COWLEY 1918–1920
G. A. MILLER 1918–1920, 1922–1924,
E. J. WILCZYNSKI 1918–1919, 1922–
L. P. EISENHART 1919–1922, 1925–
E. V. HUNTINGTON 1917, 1919–
E. L. DODD 1920
R. D. CARMICHAEL 1920, 1924–
A. A. BENNETT 1921
H. L. RIETZ 1921–1923, 1925–
C. F. GUMMER 1921–
A. B. CHACE 1924–
DUNHAM JACKSON 1923
CLARA E. SMITH 1923–

CHARGE-OUT SLIP